How We Teach: Transport Phenomena and Related Courses

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Abstract

In 2014, the AIChE Education Division’s Course Survey Committee supervised a survey on how Transport Phenomena and related courses are taught by different institutions. Faculty members from chemical engineering departments who have taught these courses during the 2013-2014 academic provided the responses. The survey, which was conducted online using the software Qualtrics, was disseminated to faculty members by department administrators who were solicited via email. The survey covered topics ranging from course content, student learning objectives, and textbook preferences. In this paper, statistical results from the survey are provided, as well as a comparison with results obtained from related surveys previously conducted in 1977, 1978, and 1987.

Introduction

Beginning in 1957, a series of surveys regarding the instruction of courses in the undergraduate chemical engineering curriculum were overseen by the AIChE Special Projects Committee. While these surveys covered courses ranging from kinetics to mass transfer, their distribution ended in the late 1990s. In 2008, the AIChE Education Division was established. Within the division, a Course Survey Committee was formed to continue the development, distribution, and analysis of these surveys. The AIChE Education Division recognized the value of the survey for its characterization of how courses are taught at a broad range of institutions as well as for the opportunity to share innovative and effective teaching methods associated with specific courses. This paper presents the results from the most recent survey on Transport Phenomena and related courses, which was administered by the AIChE Education Division Course Survey Committee. In addition, the results from this survey are compared to previous transport phenomena related surveys conducted in 1977 (Fluid Flow and Heat Transfer)\(^2\), 1978 (Mass Transfer)\(^3\), and 1987 (Mass Transfer)\(^4\).

Transport Phenomena or related courses, is a required set of courses in chemical engineering curricula. In additions, topics that involve Transport Phenomena are found in almost fifty percent of chemical engineering journals\(^1\). Thus, there is a need to understand how institutions address the course structure and pedagogy behind these courses.

Survey Background

The Transport Phenomena and Related Courses Survey was designed, disseminated, and analyzed in 2014. In developing the survey, previous surveys conducted in 1977 (Fluid Flow and Heat Transfer), 1978 (Mass Transfer), and 1987 (Mass Transfer) were reviewed, particularly for questions that can be posed in 2014 for comparative purposes. Unlike the previous surveys, the 2014 survey was not developed for one specific course (e.g. mass transfer). The members of the Course Survey Committee developed the 2014 survey to be as robust as possible; thus, the survey could be completed by instructors who teach fluid mechanics, heat transfer, mass transfer, transport phenomena, transport operations, or other similar courses. In addition, multiple entries were allowed for courses that comprised a “sequence.” For example, if a school’s transport
curriculum included a course on fluid mechanics, and a subsequent course on heat and mass transfer, two survey entries were allowed. Survey questions were also chosen to allow for comparisons with other recent course surveys.5

The survey was conducted online using Qualtrics software hosted by Bucknell University. Email invitations were sent in late spring 2014 to all department chairs requesting participation from the faculty members who teach courses in the transport phenomena sequence. Similarly, follow-up email invitations were sent in late summer 2014.

A total of 86 unique survey replies were obtained from 72 instructors from 59 different institutions. Some institutions had multiple responses due to multiple faculty members teaching courses in their transport related sequence. A list of all replying institutions can be found in Appendix B. All replies were from institutions within the United States except one from Lagos (Lagos State Polytechnic).

Due to the complexity of the survey, the results were broken down into different sections: Program/Department Characteristics, The “First” Course (Fluid Mechanics), The “Second” Course (Heat [and Mass] Transfer), and The “Third” Course (Mass Transfer [and Separations]. Some data was available for a “fourth” course (solely separations) and was not included in the analysis. It is important to note that while these subdivisions do reflect the bulk of the survey replies, some overlap in the results does exist due to the wide range of course variations.

Program/Department Characteristics

Faculty size per department

The replies from the survey represented 59 different institutions from around the world. As can be seen in Figure 1, there is a significant representation of departments of varying size. Most of the survey replies came from departments ranging from 6-40 faculty members. However, a few departments with faculty numbers either less than 5 or greater than 41 were represented.

![Figure 1 - Number of faculty per department](image-url)
Number of graduates from program

The universities surveyed encompassed a wide range of student body sizes. These results represent graduates from the programs, not enrolled students. While there were extremes in sizes, less than 20 students to more than 180 students, more than half (~57%) of the departments graduate 21-60 students.

Figure 2 - Number of graduates from program

Number of transport courses in sequence

The number of transport courses in the institution’s transport phenomena sequence ranged from two to five courses. It is interesting to note that not one university reported as requiring a single transport phenomena course as part of their curriculum. Instead, for all institutions responding, a distinct sequence of courses is required. Some institutions reported requiring separations as part of their transport-related sequence. Though not required, other institutions did not report about their separations course. More than 80% of the responding institutions replied that their transport phenomena sequence consists of 2-3 courses.

Figure 3 - Number of transport courses in sequence
Other program and department characteristics were also surveyed. In terms of departmental degree programs, approximately 85% of the universities offered only one degree (chemical engineering), while the remaining 15% offered additional degrees (e.g. biochemical engineering, materials science). In addition, approximately 90% of the universities operated on the semester system, while the remaining 10% operated on the quarter system.

The “First” Course – Fluid Mechanics

Courses that focused on Fluid Mechanics represented 95% of the first courses offered by the responding programs. Figure 4 shows the titles of the first courses in the transport phenomena sequences. 70% of the responses had the words “fluid mechanics” in the course title. Responses under “Other” include course titles such as Transport Phenomena 1 and Transport Processes (Operations) 1. For those courses, fluid mechanics formed the bulk of the course content.

![Figure 4 - Title of the first course in the transport sequence](image)

Sophomore and juniors were the primary audience for this course. None of the programs indicated that freshman or seniors were taught fluid mechanics. Approximately 2/3rd of the programs taught fluid mechanics to juniors, while the remaining 1/3rd of the programs taught the course to sophomores.

Balance/Orientation of Content

The survey asked if the course content was focused on transport theory, unit operations, or a combination of both approaches. The results for this question given in 2014 can be seen in Figure 5 and the results from 1977 can be seen in Figure 6. In 2014, transport theory was the most common orientation of course content (44%), while a combination of transport theory and unit operations was also common (43%). This is in contrast to the results from 1977, where the unit operations approach was the most common (37%). This shift in course approach can be attributed to the incorporation of purely transport phenomena (i.e. mathematically-focused) courses into the undergraduate curriculum, as well as the introduction of separate unit operations
and separations-based courses later in the curriculum. This shift in approach is also noticed in the types of textbooks required for this course.

**Figure 5** - Balance/orientation of fluid mechanics course content (2014)

**Figure 6** - Balance/orientation of fluid mechanics course content (1977)

*Textbooks*

Approximately 15 different textbook choices were listed as the primary textbook for the fluid mechanics course. Figure 7 shows the different textbooks assigned. A complete list of the textbook information can be found in Appendix C. Due to the variability of editions assigned, only authors and titles are noted in Appendix C.
From the above figure (figure 7), it can be seen that the most popular textbook assigned to teach fluid mechanics was “Transport Phenomena” by Bird, Steward, and Lightfoot. The other most popular textbook assigned were “Transport Processes and Separation Process Principles” by Geankoplis, “Fundamentals of Fluid Mechanics” by Munson, “Momentum, Heat and Mass Transfer” by Welty et al., and “Fluid Mechanics for Chemical Engineers” by Wilkes. The above figure shows the high degree of variability that instructors use in choosing a textbook for this course. A few instructors chose to use their own original notes instead of a textbook.

The following figure (figure 8) shows the textbook data from 1977 (only percentages were available from the previous survey). In 1977, the most popular textbook assigned (30%) was “Unit Operations of Chemical Engineering” by McCabe and Smith. The second most popular textbook assigned (20%) was “Momentum, Heat and Mass Transfer” by Bennett and Myers. It is interesting to note that in 2014, these two texts are no longer the most popular textbooks assigned. This is also the case for “Fluid Mechanics” by Streeter, which was 7% of the textbooks assigned in 1977, but is no longer assigned.
Classroom structure

Instructors were also surveyed regarding aspects of their classroom structure (e.g. number of lecture hours, etc…) Approximately 84% of the fluid mechanics classes meet for three hours a week. 10% of the classes meet for four hours a week, and other classes ranged from two to nine hours a week. Only approximately 12% of the classes met weekly for a separate laboratory (not computational) activity or recitation. 74% of the classes only met for lecture, while the rest of the classes met additionally for a recitation or computation laboratory.

The primary system of units used was a combination of SI and English units (58%). For the remaining courses, only SI units were used (42%). No class used only English units. These results are in contrast to the units of measure used in 1977. In 1977, mixed units were used in 68% of the courses, SI units were used in 5% of the courses, and English units were used in 27% of the courses. Thus from 1977 to 2014, there has been a dramatic shift to move away from English-only units of measure for fluid mechanics courses.

Computer Use

Figure 9 shows the percentage of computational assignments used in fluid mechanics courses. As can be seen from the figure, approximately 70% of the classes responded that 1-25% of the assignments given involve the use of a computer.
The “Second” Course – Heat (and Mass) Transfer

Courses that focused on content on Heat and/or Transfer represented approximately 100% of the second courses offered by the responding programs. Figure 10 shows the titles of the second course in the transport phenomena sequences. 69% of the responses had the words “heat or mass transfer” in the course title. Responses under “Other” include course titles such as Transport Phenomena 2 and Transport Processes (Operations) 2. For those courses, heat and/or mass transfer formed the bulk of the course content.

Figure 9 - Percent of fluid mechanics assignments involving a computer (2014)

Figure 10 - Title of the second course in the transport sequence
Juniors were the primary audience for this course (94%). None of the programs indicated that freshmen were taught heat and/or mass transfer. Approximately 6% of the courses were taught to sophomores or seniors.

**Balance/Orientation of Content**

The survey asked if the course content was focused on transport theory, unit operations, or a combination of both approaches. The results for this question given in 2014 can be seen in Figure 11 and the results from 1977 can be seen in Figure 12. In 2014, a combination of transport theory and unit operations was the most common orientation of course content (61%), while transport theory was the second most common orientation (26%). A unit operations approach was found in only 9% of the courses. This is in contrast to the results from 1977, where the unit operations approach was the most common (40%). Transport theory was the second most common orientation (35%). This shift in approach was also observed in the fluid mechanics course. This shift in approach is also noticed in the types of textbooks required for this course.

**Figure 11 - Balance/orientation of heat and/or mass transfer content (2014)**

**Figure 12 - Balance/orientation of heat and/or mass transfer content (1977)**
**Textbooks**

Approximately 14 different textbook choices were listed as the primary textbook for the heat and/or mass transfer course. Figure 13 shows the different textbooks assigned. A complete list of the textbook information can be found in Appendix C.

![Textbook Assignments](figure13)

**Figure 13 - Textbooks assigned for Heat and/or Mass Transfer (2014)**

From the above figure it can be seen that there is no singular popular textbook. The three most popular textbook assigned were “Transport Processes and Separation Process Principles” by Geankoplis, “Introduction to Heat Transfer” (or “Fundamentals of Heat and Mass Transfer” by Incropera, et al., and “Momentum, Heat and Mass Transfer” by Welty et al.”. The above figure shows the high degree of variability that instructors use in choosing a textbook for this course. A few instructors chose to use their own original notes instead of a textbook.

The following figure (figure 14) shows the textbook data from 1977 (only percentages were available from the previous survey). In 1977, the most popular textbook assigned (32%) was “Unit Operations of Chemical Engineering” by McCabe and Smith. The second most popular textbook assigned (15%) was “Momentum, Heat and Mass Transfer” by Bennett and Myers. It is interesting to note that in 2014, these two texts are no longer the most popular textbooks assigned. This is also the case for “Heat Transfer” by Holman, which was 13% of the textbooks assigned in 1977, but is no longer assigned.
Instructors were also surveyed regarding aspects of their classroom structure (e.g. number of lecture hours, etc…). Approximately 70% of the heat and/or mass transfer classes meet for three hours a week. 18% of the classes meet for four hours a week, and other classes ranged from one to nine hours a week. Only approximately 11% of the classes met weekly for a separate laboratory (not computational) activity or recitation. 77% of the classes only met for lecture, while the rest of the classes met additionally for a recitation or computation laboratory.

The primary system of units used was a combination of SI and English units (53%). For the remaining courses, only SI units were used in 45% of the courses and only English units were used in 2% of the courses. These results are in contrast to the units of measure used in 1977. In 1977, mixed units were used in 68% of the courses, SI units were used in 5% of the courses, and English units were used in 27% of the courses. Thus, like for the fluid mechanics courses, from 1977 to 2014, there has been a dramatic shift to move away from English-only units of measure for heat and/or mass transfer courses.

Computer Use

Figure 15 shows the percentage of computational assignments used in heat and/or mass transfer courses. As can be seen from the figure, approximately 74% of the classes responded that 1-25% of the assignments given involve the use of a computer.
Courses that focused on content on Mass Transfer (and Separations) represented approximately 100% of the third courses offered by the responding programs. Figure 16 shows the titles of the third courses in the transport phenomena sequences. Since not all programs have three courses in the transport sequence, the number of responses for this course was 23, as compared 67 for the first course. 83% of the responses had the words “mass transfer” in the course title.
Juniors (61%) and seniors (30%) were the primary audience for this course. None of the programs indicated that freshmen were taught mass transfer (and separations).

**Balance/Orientation of Content**

The survey asked if the course content was focused on transport theory, unit operations, or a combination of both approaches. The results for this question given in 2014 can be seen in Figure 17 and the results from 1987 and 1978 can be seen in Figures 18 and 19, respectively. In 2014, a combination of transport theory and unit operations was the most common orientation of course content (74%), while unit operations was the second most common orientation (17%). A transport theory approach was found in only 9% of the courses.

This is in contrast to the results from 1987 and 1978, where the unit operations approach was the most common approach, 53% and 43%, respectively. A combination of unit operations and transport theory was the second most common orientation, 38% and 30%, respectively. This shift in a reduction of unit operations was also observed in the fluid mechanics and heat and/or mass transfer courses. This shift in approach is also noticed in the types of textbooks required for this course.

![Figure 17 - Balance/orientation of mass transfer (and separations) content (2014)](image-url)
Textbooks

Approximately 7 different textbook choices were listed as the primary textbook for the mass transfer (and separations) course. Figure 19 shows the different textbooks assigned. A complete list of the textbook information can be found in Appendix C.
From the above figure it can be seen that two textbooks are the most popular. The most popular textbooks are “Transport Processes and Separation Process Principles” by Geankoplis and “Separation Process Principles” by Seader, et al. Compared to fluid mechanics and heat and/or mass transfer, there is less variety in the textbooks assigned. No instructor chose to use his or her own original notes instead of a textbook.

The following figures (figures 20 and 21) show the textbook data from 1987 and 1978, (only percentages were available from the previous survey). In both 1987 and 1978, the most popular textbooks assigned were “Unit Operations of Chemical Engineering” by McCabe and Smith and “Mass-Transfer Operations” by Treybal. For both those surveys, those two books represented 40-50% of the textbooks assigned. It is interesting to note that in 2014, these two texts are no longer the most popular textbooks assigned. In particular, no instructor assigned the previously popular textbook by Treybal.
Instructors were also surveyed regarding aspects of their classroom structure (e.g. number of lecture hours, etc...) Approximately 61% of the mass transfer (and separations) classes meet for three hours a week. 13% of the classes meet for two hours ad week and 17% met for four hours a week. Other classes ranged from six to nine hours a week. Only approximately 13% of the classes met weekly for a separate laboratory (not computational) activity or recitation. 83% of the classes only met for lecture, while the rest of the classes met additionally for a recitation or computation laboratory.
The most common systems of units used were the SI system (52%) and a combination of SI and English units (48%). No course solely used English units.

Computer Use

Figure 22 shows the percentage of computational assignments used in mass transfer (and separations) courses. As can be seen from the figure, approximately 64% of the classes responded that 1-25% of the assignments given involve the use of a computer.

![Figure 22 - Percent of mass transfer (and separations) assignments involving a computer (2014)](image)

Conclusions

The Transport Phenomena course sequence is a fundamental sequence of courses in the chemical engineering curriculum and has seen a significant shift in its pedagogical approach over the past 30-40 years. In particular, there has been a significant shift from teaching the course from solely a unit operations approach to one that includes transport theory. This is also represented in the textbooks assigned. An increasing amount of textbooks with larger sections on transport phenomena theory are being assigned as opposed to textbooks primarily on unit operations theory. In addition, there has been a shift in using only English units to courses that involve using mixed English and SI units.

The survey results show that the most common classroom structure for these types of courses involve three-hour lectures (with little or no recitation or laboratory/computational recitation). In addition, for most transport courses, computer assignments are required for approximately 25% of the assignments given.

The survey results also highlight the multitude of ways in which the transport phenomena sequence can be taught. This is supported by the variation of course titles, variability in classroom audience, and the wide-range of textbooks currently being assigned.
The survey results will contribute to the advancement of chemical engineering education by helping to inform instructors about the pedagogical history behind teaching transport related courses as well as the current practices observed and textbooks being assigned.

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References

Appendix A – Survey

Program/Department Characteristics

1 – Name of your institution

2 – Faculty name

3 – Department name

4 – Faculty members per department

5 – Does the department offer more than one degree?

6 – How many undergraduates graduated from program?

7 - Does your institution use quarters/ trimesters, semesters, or another system?

8 - How many courses are in your transport sequence?

First (Second and Third) Course in Transport Sequence

1 - What is the title of this course?

2 - Who is the primary audience for this course?

3 - On balance, how is your course content oriented?

4 - On balance, how is your course content oriented?

5 - How many hours does this course meet for "lecture" weekly?

6 - How many hours does this course meet for "laboratory" (not / computational) weekly?

7 - How many hours does this course meet for / either recitation or computational laboratory weekly?

8 - Does this course regularly meet for any other purpose (example: studio)?

9 - What percent of the assignments require use of a computer?

10 - If possible, please cut-and-paste the course objectives into this / space (as given in the syllabus or ABET documentation).
Appendix B – Institutions

Auburn University
Brigham Young University
Brown University
Bucknell University
Cal Poly Pomona
Colorado State University
Florida Institute of Technology
Georgia Institute of Technology
Kansas State University
Kettering University
Lagos State Polytechnic
Lehigh University
Louisiana Tech University
Michigan Technological University
Mississippi State University
Missouri University of Science & Technology
New Jersey Institute of Technology
New Mexico Tech
North Carolina State University
Northwestern University
NYU Polytechnic School of Engineering
Ohio State University
Ohio University
Pennsylvania State University
Purdue University
South Dakota School of Mines and Technology
Texas A&M University
The Cooper Union
Tulane University
University of Arizona
University of Arkansas
University of California at Berkeley
University of Florida
University of Houston
University of Illinois, Urbana-Champaign
University of Iowa
University of Kentucky
University of Kentucky (Lexington)
University of Maryland
University of Minnesota Duluth
University of New Mexico
University of Notre Dame
University of South Alabama
University of Southern California
University of Toledo
University of Tulsa
University of Wisconsin
University of Wisconsin-Madison
Villanova University
Washington State University
West Virginia University
Appendix C – Textbooks

Fluid Mechanics
Bird, Stewart, Lightfoot. “Transport Phenomena”
Crowe. “Engineering Fluid Mechanics”
De Nevers. “Fluid Mechanics for Chemical Engineers”
Denn. “Process Fluid Mechanics”
Fox and McDonald. “Introduction to Fluid Mechanics”
McCabe, Smith, Harriott. “Unit Operations of Chemical Engineering”
Middleman, “An Introduction to Fluid Dynamics”
Morrison, “An Introduction to Fluid Mechanics”
Munson, “Fundamentals of Fluid Mechanics”
Welty, Wicks, Wilson, Rorrer. “Momentum, Heat and Mass Transfer”
Wilkes. “Fluid Mechanics for Chemical Engineers”

Heat and/or Mass Transfer
Bird, Stewart, Lightfoot. “Transport Phenomena”
Crosby. “Experiments in Transport Phenomena”
Hagen. “Heat Transfer with Applications”
Kreith. “Principles of Heat Transfer”
McCabe, Smith, Harriott. “Unit Operations of Chemical Engineering”
Middleman, “An Introduction to Fluid Dynamics”
Mills. “Heat Transfer”
Seader, Henley, Roper. “Separation Process Principles”
Welty, Wicks, Wilson, Rorrer. “Momentum, Heat and Mass Transfer”

Mass Transfer (and Separations)
Bird, Stewart, Lightfoot. “Transport Phenomena”
Cussler. “Diffusion”
McCabe, Smith, Harriott. “Unit Operations of Chemical Engineering”
Seader, Henley, Roper. “Separation Process Principles”
Welty, Wicks, Wilson, Rorrer. “Momentum, Heat and Mass Transfer”