The Organization of Transport Topics in Chemical Engineering Curricula

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Abstract

This paper presents results from a preliminary survey of 35 chemical engineering departments over transport phenomena and applications. These include momentum, energy, and mass transfer as well as rate-based and equilibrium-based separations. Departments have an average of 3.4 required semester courses in transport phenomena and applications (median 3). The first transport course taken in the series (32 described) is typically a fluids-only course (53%) with some departments adding heat transfer (19%) or heat & mass transfer (13%). The second transport phenomena course (31 described) is more variable, with 35% being a heat & mass transfer course; 19% being fluids, heat, & mass transfer; and 13% each for mass transfer & separations and heat transfer only. Subsequent courses focus on mass transfer & separations (50% of 3rd courses and 33% of 4th courses), with separations alone accounting for 33% of 4th courses. In terms of practical applications, pipe network design and/or pump sizing is taught at 88% of 32 institutions, but heat exchanger design is taught at 97% of those institutions. Rate-based and equilibrium-based separations applications are both taught at 91% of responding institutions. These results are presented to allow departments to benchmark themselves against domestic institutions.

Keywords

Chemical Engineering, Fluid Mechanics, Heat Transfer

Introduction and Methods

The Course Survey Committee of the Education Division of AIChE surveys chemical engineering departments in the US and Canada each fall about a specific course or course series The Fall 2024 topic is transport phenomena and applications, including fluid mechanics, heat transfer, and mass transfer. Equilibrium-based separations were also included as a related topic not covered in another survey. This topic was last surveyed by the committee in 2014. [1] Because this is a complex set of topics which may be taught in several courses with various configurations, we completed a preliminary survey in Spring 2024. This preliminary survey asked how many required courses of transport phenomena and applications are in the program and which of 15 different topics were in each of these required courses.

Responses were solicited by email newsletters for the AIChE Education Division and the ASEE Chemical Engineering Division as well as the AIChE Education Division's chairs listserv.

Responses were received from the 35 institutions listed in the Appendix. All the respondents use the semester system, and 91% of the responses were for chemical engineering degree programs.

Results

The distribution of the number of courses in the transport phenomena and applications series is given in Figure 1. The average number of courses was 3.4 with a median of 3. The survey in 2013 did not consider applications, particularly separations, within its scope. In 2014, the transport series without applications was 2 – 3 courses, with 4 or 5 courses at a few institutions.

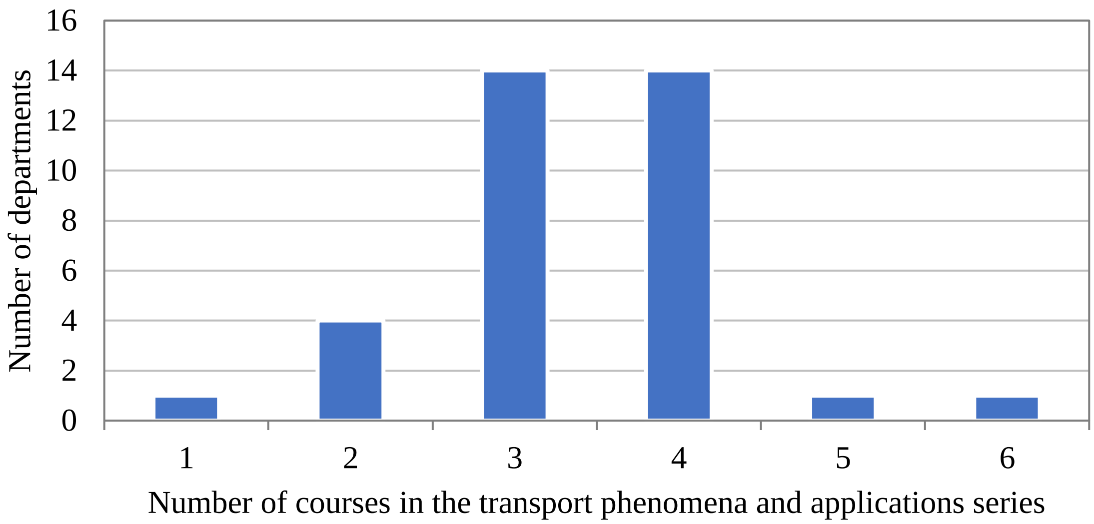

Figure 1. Distribution of the number of courses in the transport phenomena and applications series, out of 35 reporting institutions.

Departments were asked to select the topics from Table 1 covered in each course of their transport and applications series. These topics were presented in a different order which emphasized the similarity across momentum, energy, and mass transfer. The topic order is indicated by the number with each topic in Table 1. Only 32 of the responding departments described their courses. For the analysis of this paper, these 15 topics were grouped into subjects for fluid mechanics, heat transfer, mass transfer, and separations. Each course was then categorized as containing fluid mechanics if it included any of the topics listed in the Fluid Mechanics column of Table 1, and so on for the other topics.

The subjects covered in the first course in the transport series are presented in Figure 2. The pie slices in this figure and those to follow are organized in the same order, starting at twelve o'clock: first by how many subjects are within the course and second by fluid mechanics, heat transfer, mass transfer, and separations. Fluid mechanics is the theme of the first course. Over half of the responding institutions teach only fluid mechanics in their first transport course. Another third of the institutions add heat transfer and/or mass transfer to fluid mechanics for the first course. Only 9% of the institutions do not cover fluid mechanics in their first transport course. These results are quite similar to those in 2014, when fluid mechanics represented 95% of the first courses and 60% were fluid mechanics courses.

Table 1. Topics that may appear in transport phenomena and applications courses, grouped into possible subjects. The numbers give order in which the topics were listed in the survey.

Fluid Mechanics (Fluids)	Heat Transfer (Heat)	Mass Transfer (Mass)	Separations
1. Fluid basics (properties, statics)	5. Conduction (Fourier's law, heat transfer rate, extended surfaces, boundary layer)	6. Diffusion (Fick's law, eq-ns to calculate diffusion: Wilke-Chang, Leonard-Jones)	2. Vapor-liquid equilibrium (phase diagrams, equations of state)
3. 1-D incompressible flow (Bernoulli, pipe flow)	7. Convection (forced vs free, Newton's law of cooling, lumped capacity)	8. Convection (Sherwood #, MT coefficients, fluid boundary layer)	14. Rate-based separations applications
4. Multi-dimensional flow (Navier-Stokes, differential analysis)	11. Radiation (black body radiation, Stephan-Boltzman Law)	9. Conservation equations/Fundamentals (two-film theory, concentration gradients)	15. Equilibrium-limited separations applications
12. Pipe network design and/or pump sizing	13. Design of heat exchangers (double pipe, shell & tube, plate on plate, overall heat transfer coefficient)	10. Rate-based separations theory	

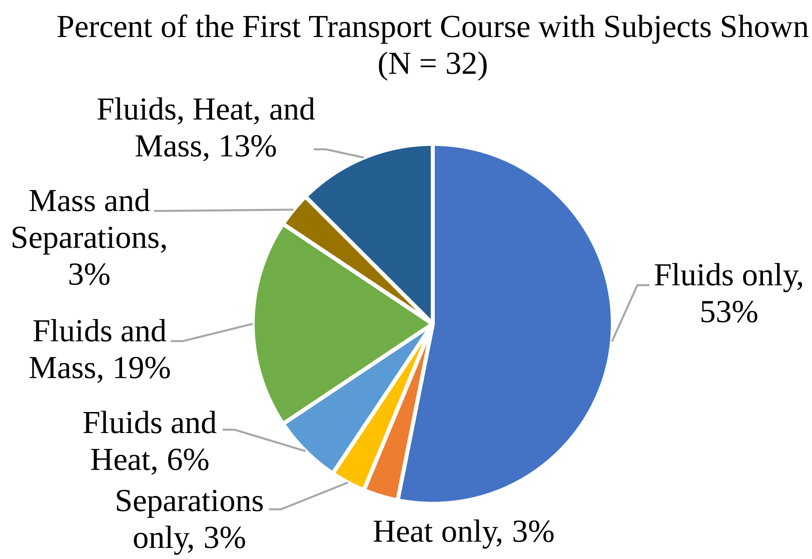

Figure 2. Distribution of subjects in the first transport course, as grouped in Table 1.

The themes of the second transport course are heat transfer and mass transfer. When all the pie slices with heat transfer Figure 3 are combined, 75% of the institutions reported heat transfer as a subject in the second course. Similarly, mass transfer is subject in 79% of the second courses.

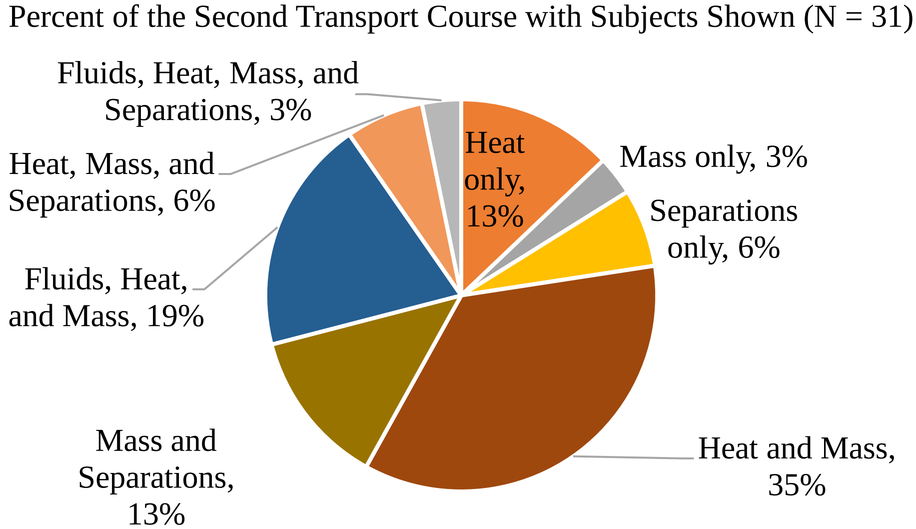

Figure 3. Distribution of subjects in the second transport course, as grouped in Table 1.

Obviously, neither heat transfer nor mass transfer is commonly taught as a single-subject course in the second transport course. The most common combinations are heat transfer with mass transfer (35% of 2nd courses) and heat transfer with fluid mechanics and mass transfer (19%). In 2014, the second transport course was also heat and/or mass transfer, but a third of the second courses were heat transfer only.

Half of the third transport courses are mass transfer & separations, as shown in Figure 4, and another 19% of the courses add fluid mechanics and/or heat transfer. Courses with heat & mass transfer make up the second largest portion of third transport courses. The emphasis of this course has changed little from 2014 when 83% of third courses had “mass transfer” in the title.

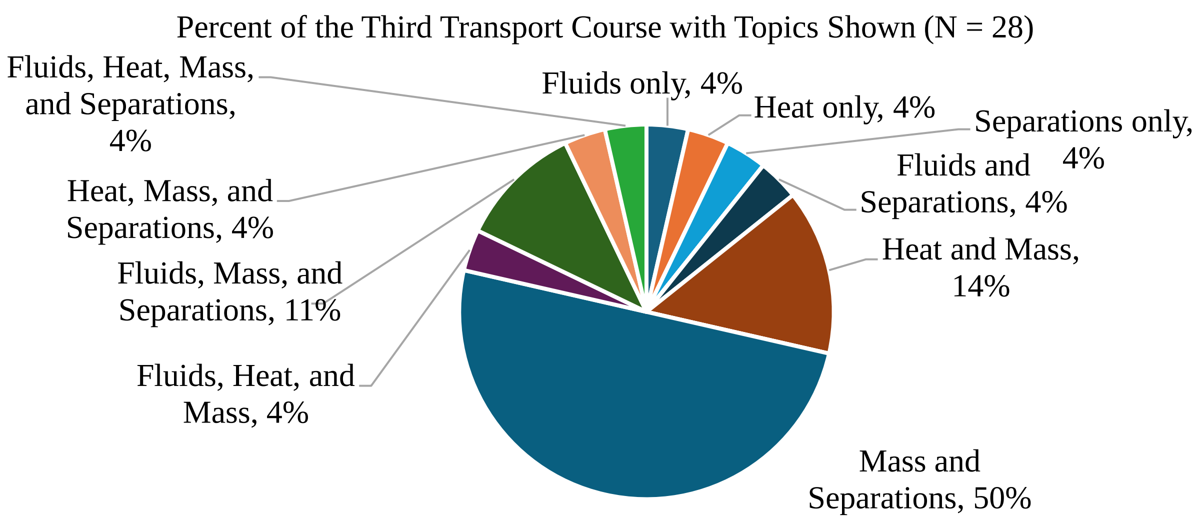

Figure 4. Distribution of subjects in the third transport course, as grouped in Table 1.

While there is a drop of only four out of 32 institutions as we moved from one to three transport courses, there is a drop of 13 in continuing to move to four transport courses. Topics are shown in Figure 5. Separations with mass transfer is the theme of fourth course: separations only and mass transfer & separations each are a third of these courses. Separations appear in 87% of the fourth transport courses, and mass transfer appears in 60% of the fourth courses. In 2014, all the fourth transport courses were separations.

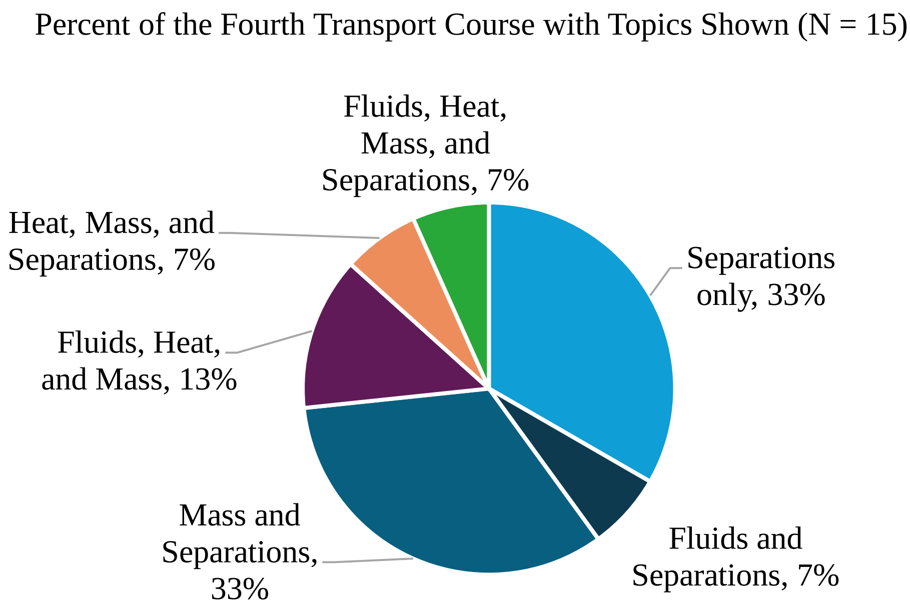

Figure 5. Distribution of subjects in the fourth transport course, as grouped in Table 1.

Two institutions reported on their fifth transport courses. One was a mass transfer & separations course, and the other was heat transfer, mass transfer, and separations. The only sixth transport course was heat transfer & separations. The 2014 paper did not report on any fifth or sixth transport courses.

The survey asked about coverage of four applications topics in the transport series: 12. Pipe network design and/or pump sizing, 13. Design of heat exchangers (double pipe, shell & tube, plate on plate, overall heat transfer coefficient), 14. Rate-based separations applications, and 15. Equilibrium-limited separations applications. Over 50% of courses in the transport series contain applications, as seen in Figure 6, and the subject areas match the themes of the different courses in the series: the first course has pipe network or pump sizing, the second course has design of heat exchangers, and later courses have both rate-based and equilibrium-based separations applications. The percentage of courses covering rate-based separations applications is about the same as that for equilibrium-based separations applications except for the fourth courses, of which there are only 15. When considered over all the institutions instead of over courses, pipe network design and/or pump sizing is taught at 88% of 32 institutions, but heat exchanger design is taught at 97% of those institutions. Rate-based and equilibrium-based separations applications are both taught at 91% of responding institutions.

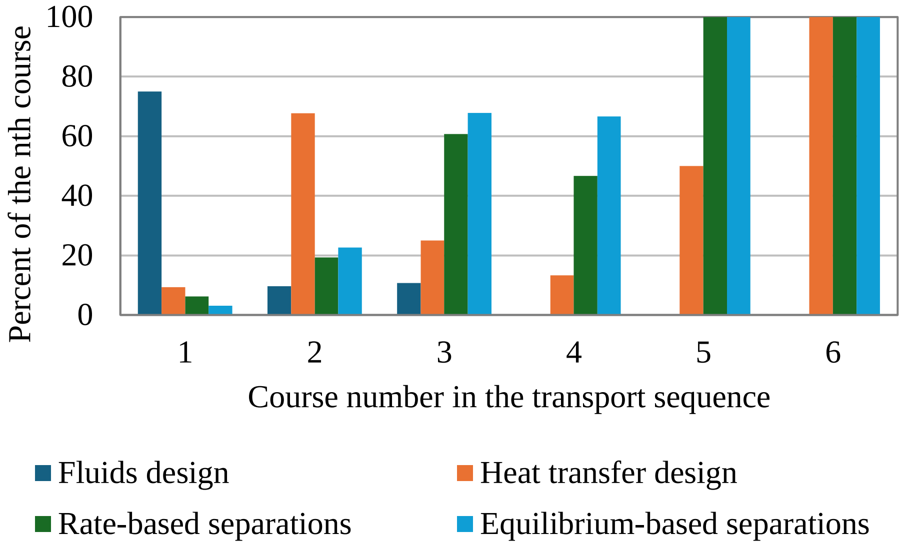

Figure 6. Applications content in the transport series

A related question in 2014 asked about the balance between transport theory and unit operations in teaching the courses. The percentage of courses oriented toward transport theory only decreased in moving from the first course to the third course in 2014: 44% fluid mechanics, 26% heat and/or mass transfer, and 9% mass transfer (and separations). In 2024, 75% of the first course in the transport series included pipe network design and/or pump sizing, which may indicate a decrease in the percentage of courses using a transport-theory-only approach in the first course (fluid mechanics) from 2014. Conversely, there may be an increase in the percentage of third courses (mass transfer & separations) using a transport-theory-only approach, as only 68% of the third courses included rate-based and/or equilibrium-based separations applications in 2024.

Follow-up Survey

The follow-up survey this fall will ask about the topics at a more granular level. We will ask about contact hours in lab, lecture, recitation, etc. to convert into credit hours for each course. Another topic will be the simulations and hands-on labs that are part of the course. Other course details included are the course timing, if one or more majors take the course, primary textbook used, and the division of course time when multiple topics are included.

Summary

The transport phenomena and applications course series in chemical engineering departments consists of 3 – 4 required courses. The first course is typically fluid mechanics. The second course is usually heat transfer and mass transfer, often in combination with each other or with another topic. The third course is mass transfer & separations. The fourth course is separations with mass transfer. The largest change since the previous survey in 2014 is a decrease in the number of heat-transfer-only courses for the second course in the series. Applications are covered in over 60% of the courses in the transport series.

References

[1] D. Lepek, M. A. Vigeant, D. L. Silverstein and J. M. Keith, "How We Teach: Transport Phenomena and Related Courses," in *ASEE Annual Conference & Exposition*, Seattle, WA, 2015.

Laura P. Ford

Laura P. Ford is an Associate Professor of Chemical Engineering at the University of Tulsa. She has degrees in chemical engineering from Oklahoma State University (BS) and the University of Illinois at Urbana-Champaign (MS and PhD). She teaches process control and chemical engineering senior labs. She advises TU's Engineers Without Borders - USA chapter. She was named a Fellow of AIChE in 2024.

Janie Brennan

Janie Brennan is a Senior Lecturer of Energy, Environmental and Chemical Engineering at Washington University in St. Louis. She earned her BS in Agricultural and Biological Engineering from Purdue University in 2010, and her Ph.D. in Chemical Engineering (also from Purdue) in 2015. She teaches several core engineering courses, including thermodynamics, separations, unit operations lab, and zymurgy, and her research has focused on understanding best practices for teaching and learning in these courses.

Heather Chenette

Heather Chenette is an Associate Professor of Chemical Engineering at Rose-Hulman Institute of Technology. Her professional interests include leveraging qualitative methods to understand and enhance student learning in the classroom and creating opportunities for students to learn about polymers, membrane materials, and bioseparation processes through research experiences.

Matthew Cooper

Matthew Cooper is a Teaching Professor in the Department of Chemical and Biomolecular Engineering at North Carolina State University where he teaches courses in Transport Phenomena, Capstone Design, Unit Operations, Thermodynamics and Material & Energy Balances. His research focuses on the development and assessment of novel methods of teaching and student engagement.

Kevin Dahm

Kevin Dahm is a Professor and Undergraduate Program Chair of Chemical Engineering at Rowan University. He earned his BS from Worcester Polytechnic Institute (92) and his PhD from Massachusetts Institute of Technology (98). He has published two books, ”Fundamentals of Chemical Engineering Thermodynamics” with Donald Visco and ”Interpreting Diffuse Reflectance and Transmittance” with his father Donald Dahm.

Jacqueline Gartner

Dr. Jacqueline Gartner is an Associate Professor in the School of Engineering at Campbell University. She received her BS in Chemistry and Math-Economics from Anderson University and a PhD in chemical engineering from Washington State University. She conducts research in engineering education on classroom and extra-curricular interventions that help students persist in engineering.

Luke Landherr

Dr. Lucas Landherr is a teaching professor in the Department of Chemical Engineering at Northeastern University, conducting research in comics and engineering education.

David Silverstein

David L. Silverstein is Chair and Professor of Chemical Engineering at the University of Mississippi. He received his BSChE from the University of Alabama and his MS and PhD in chemical engineering from Vanderbilt University. Silverstein's research interests include conceptual learning tools and training with a special interest in faculty development. He has received the following ASEE ChE Division awards: Fahien for young faculty teaching and educational scholarship, Corcoran for best CEE article (thrice), and Martin for best ChE Division paper at the ASEE Annual Meeting.

Stephen Thiel

Stephen Thiel is a Professor-Educator in the Chemical Engineering program at the University of Cincinnati (UC). He received his BS in Chemical Engineering from Virginia Tech, and his MS and PhD in Chemical Engineering from the University of Texas at Austin. His past research has focused on membrane science, adsorption, and ion exchange. He currently serves as the Chemical Engineering Undergraduate Program Director at UC and teaches the capstone process design sequence. He is a licensed Professional Engineer in the State of Ohio.

Troy Vogel

Troy Vogel is the Director of Undergraduate Studies, and Teaching Professor in the Department of Chemical and Biomolecular Engineering at the University of Notre Dame. He is the faculty advisor for ND's student chapter of AIChE.

Appendix: Survey Respondents

Auburn University
Brigham Young University
Bucknell University
California Baptist University
Christian Brothers University
Colorado School of Mines
Florida Institute of Technology
Iowa State University
Michigan State University
New Jersey Institute of Technology
New Mexico State University
North Carolina State University
Penn State
Rensselaer Polytechnic Institute
Rowan University
South Dakota School of Mines & Technology
The Cooper Union
Tulane University
University of Alabama
University of Arkansas
University of Delaware
University of Florida
University of Kansas
University of Maryland
University of Massachusetts Amherst
University of Miami
University of New Hampshire
University of South Carolina
University of South Florida
University of Toledo
University of Utah
University of Wisconsin - Madison
Wayne State University
West Virginia University
Youngstown State University