# How We Teach: Transport Phenomena and Applications

**Dr. Laura P Ford, The University of Tulsa**

Laura P. Ford is an Associate Professor of Chemical Engineering at the University of Tulsa. She teaches engineering science thermodynamics and fluid mechanics, separations/mass transfer, process control, and chemical engineering senior labs. She is an advisor for TU's student chapter of Engineers Without Borders - USA.

**Dr. Janie Brennan, Washington University in St. Louis**

Janie Brennan is a Senior Lecturer of Energy, Environmental and Chemical Engineering at Washington University in St. Louis. Her research is in chemical engineering education with a focus on process safety, lab instruction, and student engagement.

**Dr. Heather Chenette, Rose-Hulman Institute of Technology**

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.

**Dr. Matthew Cooper, North Carolina State University at Raleigh**

Dr. Matthew Cooper is a Teaching Professor in the Department of Chemical and Biomolecular Engineering at North Carolina State University where he teaches courses in Senior Design, Unit Operations, Transport Phenomena, Thermodynamics and Material & Energy Balances.

**Dr. Kevin D. Dahm, Rowan University**

Kevin Dahm is a Professor 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 Engineer

**Dr. Luke Landherr, Northeastern University**

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

**Dr. David L. Silverstein P.E., University of Mississippi**

David L. Silverstein is a Professor of Chemical Engineering and Department Chair 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.

**Dr. Stephen Ward Thiel P.E., University of Cincinnati**

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.

**Dr. Troy J. Vogel, University of Notre Dame**

©American Society for Engineering Education, 2025

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

**Jacqueline Gartner Ph.D., Campbell University**

Jacqueline Gartner is founding faculty of Campbell University's hands-on, project based chemical engineering program. She both teaches chemical engineering for the middle years and conducts research on how to create interventions to help engineering students succeed and persist to graduation.

©American Society for Engineering Education, 2025

# How We Teach: Transport Phenomena and Applications


Abstract

The AIChE Education Division Course Survey Committee's survey for Fall 2024 was transport phenomena and applications. Responses were received from 50 institutions in the United States and Canada for 94 different courses. Extra effort was made this year for Canadian responses because this year's ASEE Annual Conference is in Montreal, and we received information about seven courses from three Canadian institutions.

On average, departments have 2.4 required courses in the transport and applications series. The first course is typically momentum transfer. The second course is usually heat (and mass) transfer, possibly with momentum transfer and/or separations added. (Heat and) mass transfer is the topic for the third course when there is one.

The results that follow are based on all courses lumped together, and results are broken out by term in the paper itself. The courses are primarily junior-year courses, with 22% in the sophomore year, 71% junior year, and 7% senior year. Only 11% of the transport and applications courses offered by chemical engineering departments are multi-disciplinary. Sixty percent of the courses incorporate computational/software modeling, with Excel used in 72% of those courses, MATLAB in 47%, and Aspen Plus and Python used in 29%. Non-computational experiential components are not nearly as common as computational activities. Only 40% of the courses include experimental labs, demonstrations, and/or plant tours. Instructor demonstrations and bench-scale student-led experiments are used in over half of these courses.


## Introduction

The AIChE Education Division's Survey Committee regularly surveys courses in chemical engineering. Transport and related courses were most recently surveyed in 2014 [1], so they were due for a follow-up survey. Separations has never been surveyed by the committee or the predecessor Education Projects Committee [2]. To avoid bumping the survey cycle to 11 years to add separations to the survey list, separations was included with the transport course survey. The results of these surveys are presented so that departments may see what others are doing.

Faculty at NJIT 2017 surveyed the curriculum at 148 US institutions in 2017 [3]. Departments had a median of 7 credit hours in transport topics. The credits were divided among six different course types as described in Table 1. The majority of departments had a Fluid Flow course followed by one or more courses. They found that 22% of departments offered Fluid Flow, Heat Transfer, and Mass Transfer. Slightly more departments, 25% offered Fluid Flow followed by Heat & Mass Transfer. A smaller group, 16%, offered Fluid Flow followed by Transport Phenomena. The transport series was related to the Separations offerings in that nearly twice as many departments with a Heat & Mass Transfer course offered Separations (77%, 34/44) than those that offered Mass Transfer as its own course (42%, 25/57). Their hypothesis was that Mass Transfer and Separations contain overlapping material. This survey will focus on the transport content of courses, including how much time is spent on transport topics and which topics are covered in which courses, in addition to how many credit hours of different transport courses are required.

Table 1. Literature credit hours, frequency, and year taught for transport and separations courses. N = 148 for [3], and N = 35 for [4].

| Course Category | Median Credit Hours [3] | Percent Frequency [3] | Percent Frequency [4] | Year Taught [4] |
|---|---|---|---|---|
| Fluid Flow [3] / Mechanics [4] | 3 | 68 | 51 | 2.6 |
| Fluid & Heat Transfer | 3 | 13 | 23 | 2.8 |
| Fluid/Heat/Mass Transfer | - | - | 34 | 2.9 |
| Heat & Mass Transfer | 3 | 30 | 37 | 3.0 |
| Heat Transfer | 3 | 34 | 26 | 3.0 |
| Mass Transfer | 3 | 39 | 34 | 3.3 |
| Transport Phenomena | 4 | 42 | - | - |
| Mass Transport/Separations | - | - | 11 | 3.0 |

Rasmussen and Butterfield surveyed 35 departments who were top-ranked in the US News & World Report rankings or in the PAC-12 conference [4]. They used seven categories for transport courses, as shown in Table 1, and they may have called "Transport Phenomena" courses "Fluid/Heat/Mass Transport". The absolute numbers are different, but the trends are like those of the NJIT paper. Fluids was offered as a stand-alone class more frequently than other transport topics. Fluid & Heat transfer combination courses were less common than other combination courses. Again, this survey report in this paper will go into more detail about course contents than the Rasmussen and Butterfield paper.

A reviewer commented that this wide variety of ways that institutions cover transport is a problem for transfer students. For their sake, perhaps we should attempt to harmonize our requirements.

Methods

The AIChE Education Division (the Division) Course Survey Committee created a survey (Appendix A) in 2024 for transport phenomena and applications, including both rate-based and equilibrium-based separations. Although equilibrium-based separations is not an application of transport phenomena, it has not been surveyed in the rest of the 10-year course rotation [5], and it seemed to fit better with the survey over transport phenomena than other surveys [3].

A preliminary survey was sent to the Division's chairs' listserv in February and March 2024. This survey asked for the names and email addresses of the faculty who teach transport, application, and separations courses. The full survey in Appendix A was sent to the faculty named by the department heads/chairs in August, September, and November. A survey request was also sent to the Division's chairs' listserv, the Division's newsletter in multiple months, and the ASEE Chemical Engineering Division's newsletter. The survey request was sent directly to each Canadian department head and a few personal contacts at Canadian institutions. The survey questions asked about credit hours, year taken, how the courses are arranged, whether the course is disciplinary or multi-disciplinary, the percent of time spent on different topics, textbook, coverage of granular topics within each subject, computational/simulation activities, and non-computation experiences. The faculty had a chance to list challenges, needs in educational materials, and distinctive pedagogical features.

A total of 133 responses from 53 institutions were received. This proceedings paper focuses on the transport phenomena courses. Question 10 asked for how much time in the course was spent on fluid mechanics, heat transfer, mass transfer, separations, and other topics. Of the 133 responses, 72 spent no time on separations and were clearly "transport" courses. For this proceedings paper, the remaining courses were divided into three categories by their time spent on separations, which is shown in Figure 1. The bottom quartile of courses with separations content was <40% time on separations, and these courses were deemed "Primarily transport" courses. The mean of separations time in courses with non-zero separations time was 67%, and the median was 80%. A somewhat arbitrary (not based on median or mean) decision was made to include up to 60% time on separations in the "mixture" category: nine courses. "Primarily separations" courses were then those with >60% time spent on separations, 39 courses. Only the "primarily transport" and "mixture" courses are considered here: 94 courses from 50 institutions named in Appendix B. The combination of the "mixture" and "primarily separations" courses will be presented elsewhere.

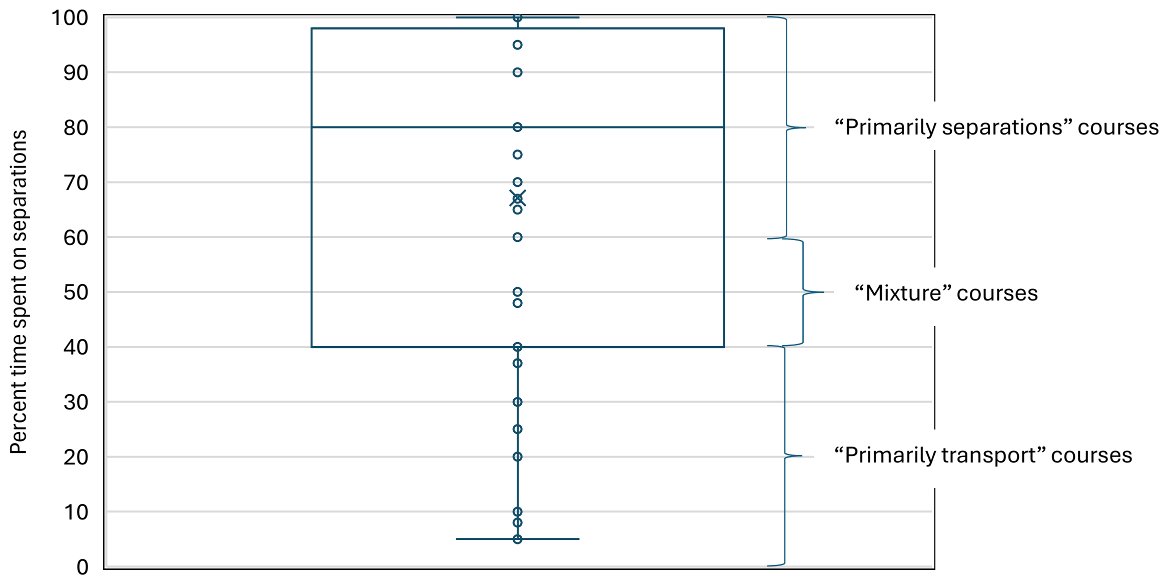


Figure 1. Distribution of time spent on separations in courses, in a box-and-whiskers plot and the division of the courses into categories marked. Only the 61 courses with non-zero separations time are included in this graph, leaving out 72 transport-only courses.

Transport courses are difficult to survey. Departments might offer one to four courses (fluid mechanics, heat transfer, mass transfer, and/or overarching transport phenomena) over one to four terms. Six [3] to seven [4] categories have been used previously to describe transport courses to prevent double-counting courses. A department might offer two transport courses together in one term. Faculty within the same department sometimes describe the series differently. As an example, the fluid mechanics professor at the main author's institution (The

University of Tulsa) and our heat transfer professor both said their courses were the first in a three-course series, even though they are typically taken in different semesters. The mass transfer professor said we didn't have a series. We have attempted to reconcile differences between faculty based on the courses included in survey responses (in the example, my institution was coded as 2-course series and the separations "mass transfer" course was removed from this report). For discussion in this paper, the courses have been divided by the term in the series. The "first-term" course is not necessarily offered in the fall term of the first year of a student's college career– this is merely the first term of the transport series, if there is one. An alternative arrangement would be to organize the courses by primary topic (fluid mechanics, heat transfer, mass transfer, binary combinations, and ternary combinations) no matter what term, and this was used a secondary organizing principle within the term structure.

## Results and Discussion Overview

The 94 courses are primarily junior-year courses, with 22% in the sophomore year, 71% junior year, and 7% senior year. This agrees well with the most recent curriculum survey in the literature [4] where any course with fluids was more frequently in the junior year than in the sophomore year and other transport courses were in the junior year. None of the nine "mixture" courses (spending only 40 – 60% of the time on transport) is in the sophomore year. Only 11% (10 courses) of the transport and applications courses offered by chemical engineering departments are multi-disciplinary. Fluid mechanics courses account for half of those multidisciplinary transport courses.

The fifty responding institutions reported one to four courses taught within the department in their transport series, as shown in Figure 2. A few institutions also have lab courses. Only one institution reported only one course (2%). That institution does have another required transport course, but perhaps that course is not taught in the department. Most common was two courses, 62% of the institutions. The report on our preliminary survey [6] specifically included separations courses. In 2014, an unreported number of departments included their separations courses as part of the transport series. In 2014, two to three courses were reported as typical, which matches well with the average of 2.4 courses for our data. There may have been a slight shift to fewer transport courses from 2014 to our 2024 final survey, but the shift to fewer courses may also be because separations courses are not included as they sometimes were in 2014.

The courses are arranged in academic terms in various ways. Departments do not all start the transport series in the same term, as indicated by only 22% of the courses being in the sophomore year. Here, "term" is a relative word, relative to the first term in the transport series at that institution. In all departments with two courses, the courses are taken sequentially with no intervening terms. None of the two-course departments reported the students taking the two courses simultaneously. Two departments had a lecture course paired with lab courses in the first term, and one of those departments had a paired lab for the second course, too.

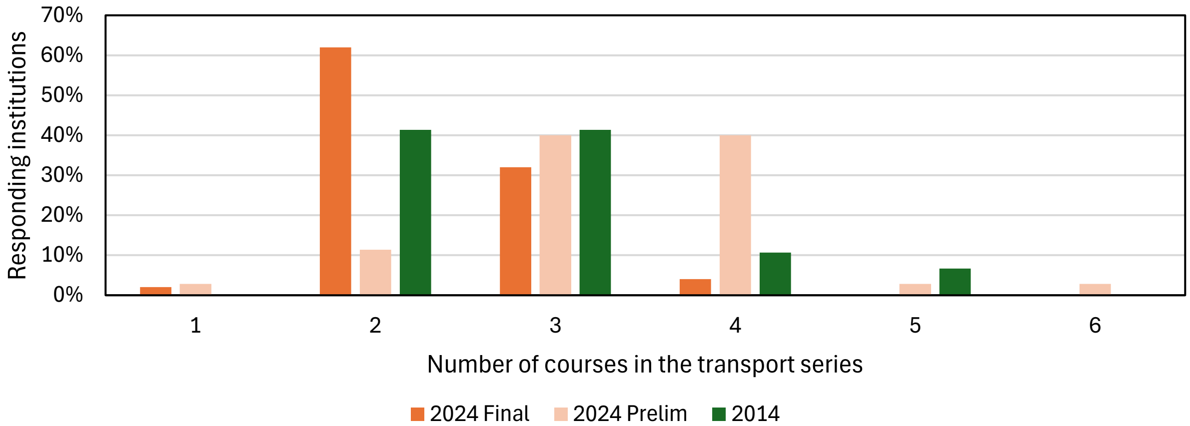


Figure 2. Number of courses in the transport series reported in 2024 Final (N = 50), 2024 Preliminary (N = 35), and 2014 (N = 75). Separations courses were excluded from the 2024 Final responses but not from the earlier surveys.

With a third course or more, the combinations of courses became more varied in the first and/or second terms (Figure 3). Each box represents a transport course, with transport labs shown in a lighter color. Departments with courses in only the first two terms are at the top, and departments with four or more courses are at the bottom. The most common arrangement is three courses spread across three sequential terms. In two departments, the students take two transport courses in the first term. In three departments, the students take two transport courses in the second term. In one department, the students take three transport courses in the second term. Two departments have transport lab courses in the first term, three in the second term, and one in the fourth term. In all departments but one, the students take the courses in sequential terms without skipping a term.

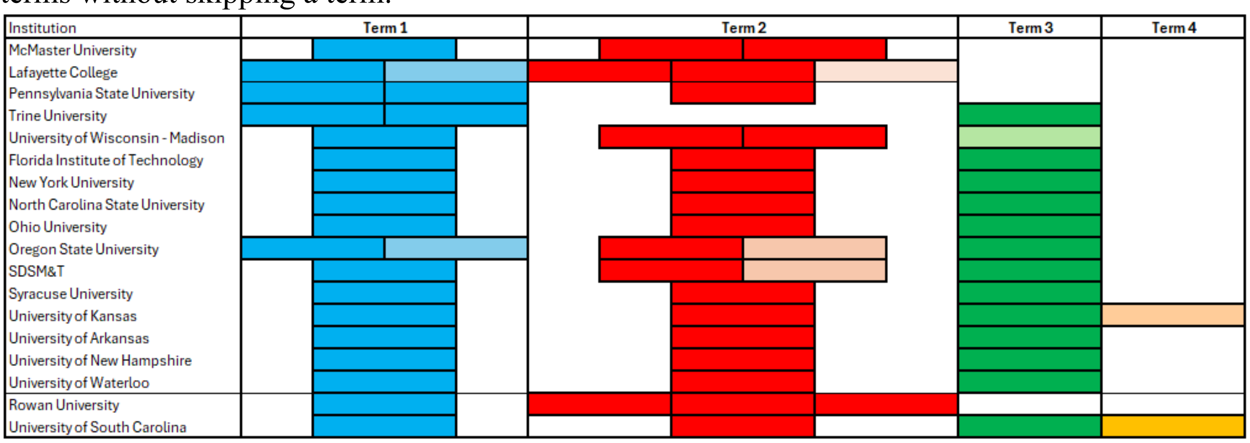


Figure 3. The arrangement of three-course and four-course transport series across academic terms. Lighter boxes indicate a transport lab course.

First-term Transport Course: Fluid Mechanics or Momentum Transport

We received responses for 41 courses taught in the first (or only) term of the transport series at 40 institutions. Eighteen of these courses (44%) are in the sophomore year, with the rest in the junior year. The timing found here matches well with the timing found by [4] for fluid mechanics courses. Only two courses (5%) are multi-disciplinary. The categorized course titles are presented in Figure 4. Courses with "Fluid Mechanics" in the title account for nearly half of the first-term courses. "Transport I" courses are then next most common, at 24%. Compared to the data from 2014, fewer courses are now called "Fluid Mechanics", and more are now taught in the sophomore year.

The reported contact hours for first-term courses in transport are presented in Table 1. Zero values were not included in the statistics. The first-term course is typically a 45 lecture-contact-hour course (3 credit hours), and a third of the courses have a recitation section which meets for 15 contact hours over the term. This matches the three credit hours for fluid mechanics found by [3].

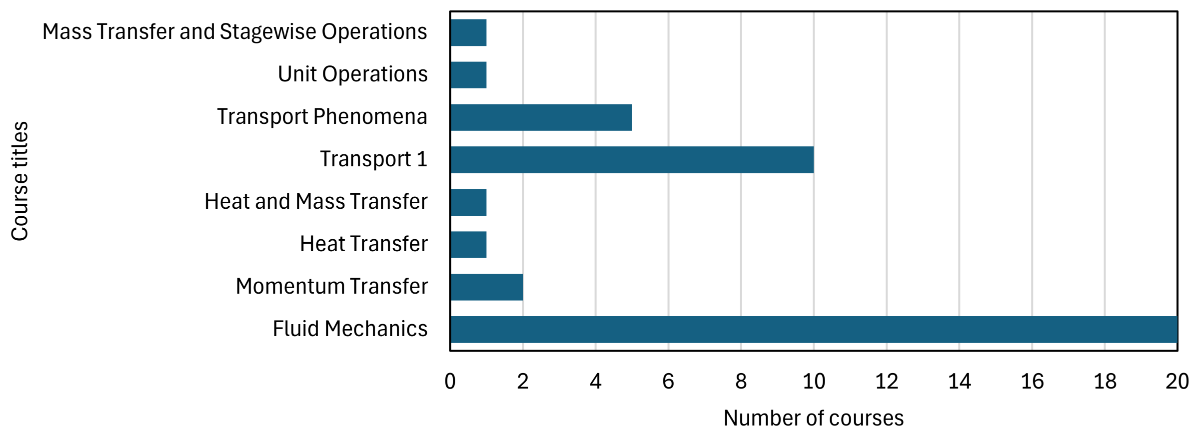


Figure 4. Course titles for first-term courses in transport. N = 41.

Table 2. Contact hours for first-term courses in transport. N = 41.

| Metric | Lab | Lecture | Recitation | Studio |
|---|---|---|---|---|
| Minimum | 7.5 | 30 | 5 | 20 |
| Median | 12 | 45 | 15 | 20 |
| Mean | 14 | 44 | 18 | 20 |
| Maximum | 24 | 60 | 30 | 20 |
| Mode | #N/A | 45 | 30 | #N/A |
| Count | 4 | 41 | 13 | 1 |

The first-term courses in the transport series are primarily fluid mechanics or momentum transport courses, as indicated by the course titles. On average, 78% of the course time is spent on fluids, 13% on heat transfer, 6% on mass transfer, 1% on separations, and 2% on other topics (balance equations, unit operations, and hydrostatics/physics). The median for time spent on fluid mechanics is 100%, as this is the case for 26 of the 41 first-term courses (63%). The remaining courses could be broken up into the following:

- 1 fluid mechanics and unit operations (50/50)

- 3 relatively-evenly distributed transport courses (although 5 are titled transport phenomena)
- 6 fluid mechanics and heat transfer courses, averaging 62% fluid mechanics
- 1 fluid mechanics and mass transfer course (90/10)
- 1 entirely heat transfer course
- 2 heat transfer and mass transfer courses
- 1 mass transfer and separations course.

We asked about many granular topics in momentum transfer, and the coverage of these topics in the first-term transport courses is shown in Figure 5. The "other" topics are non-Newtonian fluids, packed beds, and mixing time. No course covers our safety topic, relief device sizing. We considered "designing pipe networks" to be an indicator of a unit operations approach to the course and "differential analysis" to be an indicator of a transport phenomena approach. Using these rough indications, almost two-thirds of the courses use both approaches, 5% use only a unit operations approach, and about 30% use only a transport approach. This is a small shift from 2014 when 44% used a transport approach and 43% used both approaches.

The 22 "Fluid Mechanics" and "Momentum Transfer" courses (54% of first-term courses) are truly just fluid mechanics courses. Only five topics out of the heat transfer, mass transfer, and separations topics we offered were mentioned for any of these courses, and then by only one course for each topic. The discussion for heat transfer and mass transfer topics will then focus on the five "Transport Phenomena" and ten "Transport 1" courses, which is called the "transport" sub-set of the first-term courses. Only one separations topic was mentioned by one of the "transport" sub-set of first-term courses, indicating their focus on only transport.

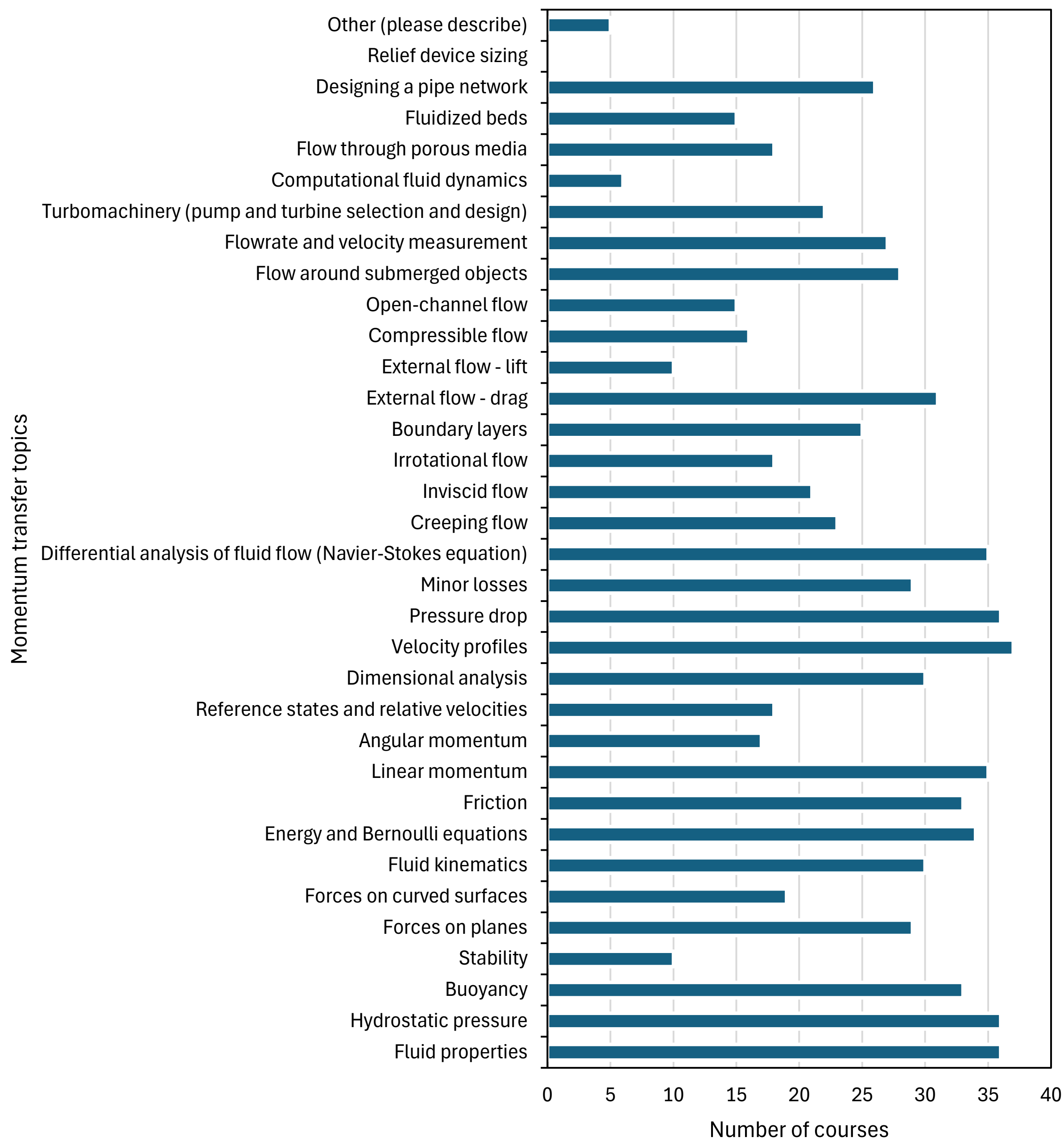


Figure 5. Momentum transfer topics covered in first-term courses. N = 41.

Figure 6 presents the coverage of heat transfer topics by the "transport" sub-set of first term courses. Over half of the "Transport 1" and "Transport Phenomena" courses cover conduction in single layers and multiple layers in series, natural convection, combined conduction and convection, and overall heat transfer coefficients. Shell balances are covered by just under half of these first-term courses with transport in the title. We hesitate to make comparisons between the "Transport 1" courses and the "Transport Phenomena" courses because the number of courses is small.

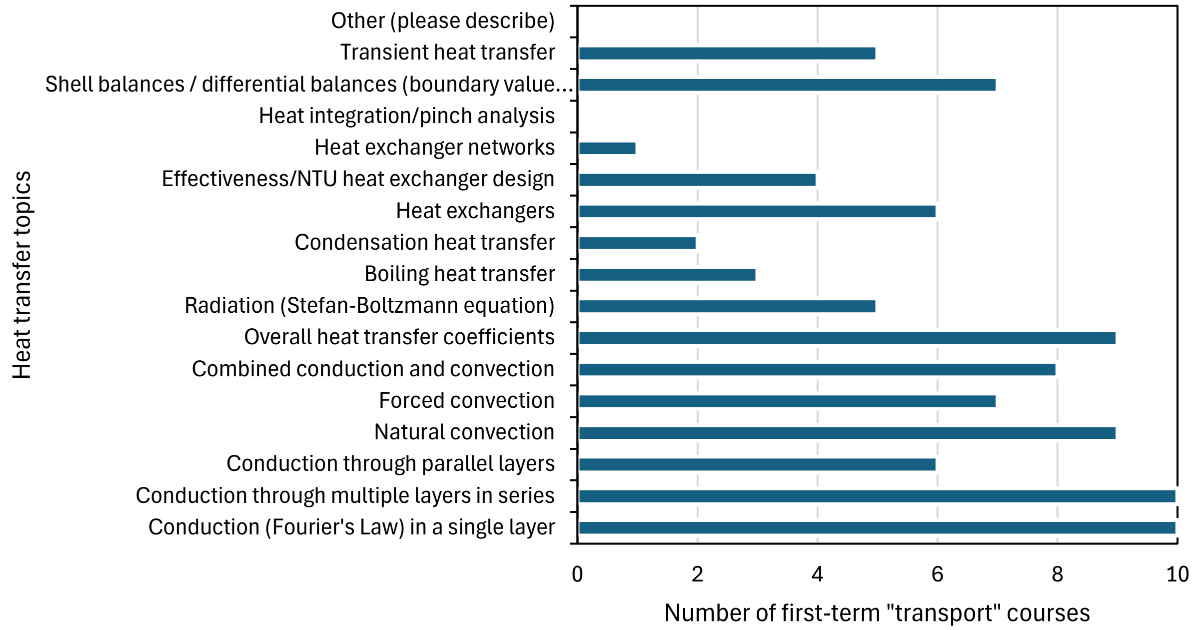


Figure 6. Heat transfer topics covered in the "transport" sub-set of first-term courses. N = 15.

Mass transfer topics are covered in under half of the "transport sub-set of first-term courses, as seen in Figure 7. Only two of the "Transport 1" courses (10%) contain mass transfer content, but those two do cover 13 to 15 of the topics we offered. That not many "Transport 1" courses cover mass transfer is reasonable if these courses are followed up by a "Transport 2" course, as indicated by the course title. "Transport Phenomena" courses in the first-term are more likely to cover mass transfer topics than "Transport 1" courses, according to our small data set.

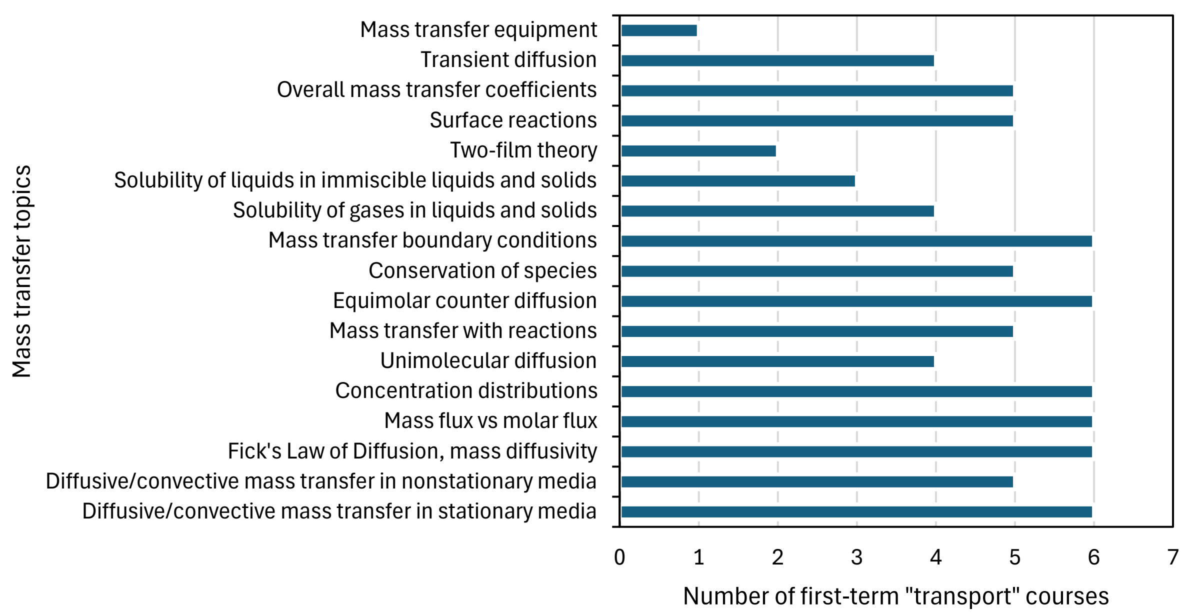


Figure 7. Mass transfer topics covered in the "transport" sub-set of first-term courses. N = 15.

The wide variety of textbooks used in the first-term transport course are shown in Figure 8. Textbooks by Bird, Cengel, de Nevers, Geankoplis, and Welty are most popular, but no textbook at all is also as popular. Since 2014, the textbooks by Munson and Wilkes are less commonly used while the textbook by Cengel is more commonly used.

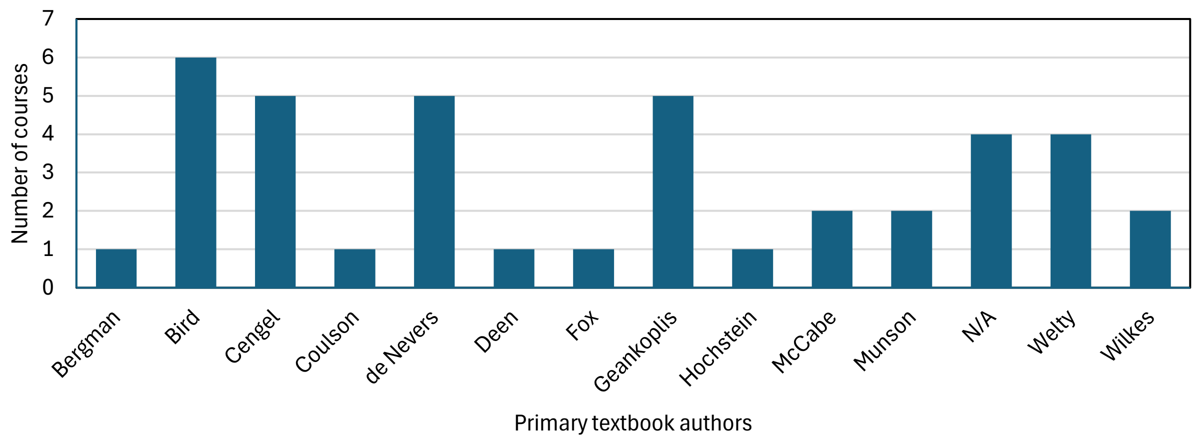


Figure 8. Textbooks used in first-term courses. N = 39.

Computational or simulation activities are done in 54% (22 of 41) first-term courses, which is lower than in any other term. Computational fluid dynamics is a topic in only six first-term courses (15%). None of these computational activities are incorporated into the course grade in 18% of the courses with them, some in 59%, and all in 23%. Excel and MATLAB are the most-commonly used packages, as seen in Figure 9, again reflecting the low coverage of computational fluid dynamics.

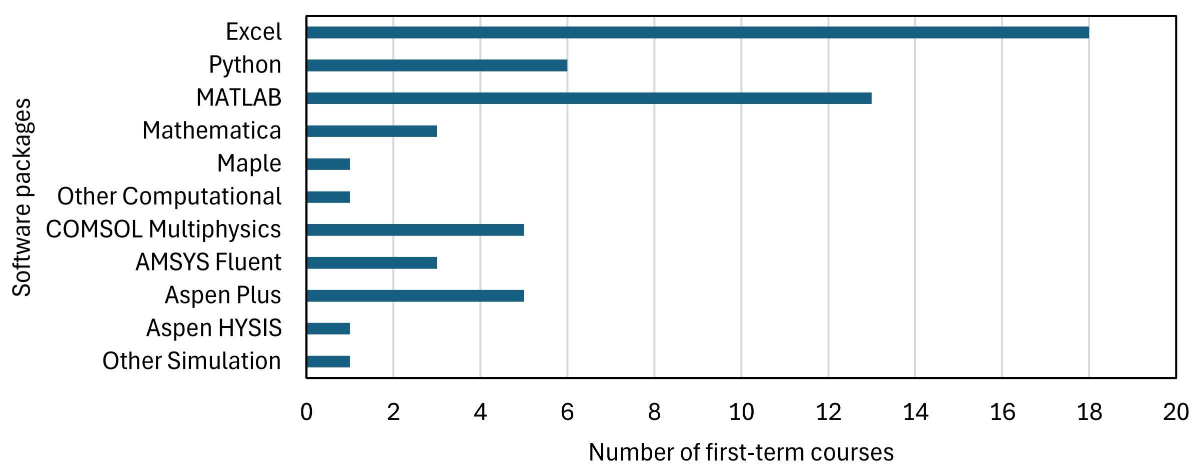


Figure 9. Software packages used in first-term courses. N = 22.

Non-computational experiential learning activities are used in 53% (21 of 40) first-term courses, which is more than any other term. None of these activities are incorporated into the course grade in 29% of the courses with them, some in 29%, most in 10%, and all in 33%. Instructor demonstrations of equipment are the most popular activity as they occurred in 70% of the courses. Bench-scale student-led experiments are in 46% of the courses, and pilot-scale student-led experiments and plant tours are both in 9% of the courses. Some other activities are YouTube videos and demonstrations with everyday materials.

Second-term Transport Course: Heat (and Mass) Transfer

Faculty reported on 38 courses taught in the second term of the transport series. Five of these courses (13%) are multi-disciplinary. Almost all (89%) of the courses are taken in the junior year with the remainder evenly split between sophomore and senior years. The course titles were categorized, and the number of courses in each category are reported in Figure 10. The variety of course titles is wider for the second-term transport courses than for the first-term courses. The most common categories are "heat and mass transfer" at 32% of the courses and "heat transfer" at 18%. This is a slight increase in "heat and mass transfer" courses from 25% in 2014 and a decrease in "heat transfer" courses from 33% in 2014.

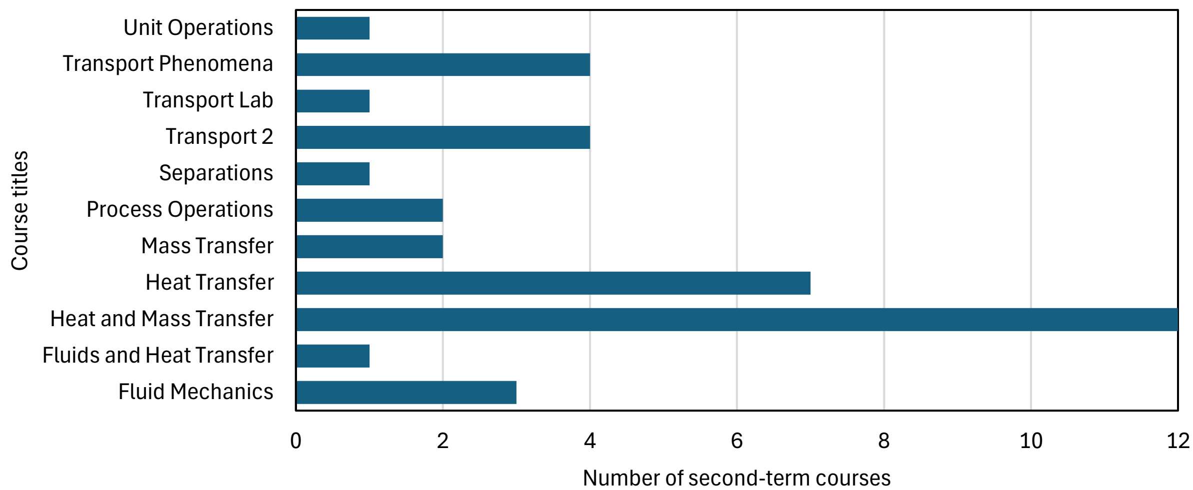


Figure 10. Number of reported second-term course titles by category. N = 38.

The reported contact hours for the course are presented in Table 3. Only non-zero hours were considered in these statistics. The courses are primarily lecture courses with 45 lecture contact hours (3 semester credit hours), and a third of the courses have recitation with 15 contact hours. Fifty-eight percent of the courses have 45 lecture contact hours, and 18% have 60 contact hours. The courses with 60 lecture hours are all heat & mass transfer and/or transport phenomena courses. Recitation contact hours are more variable, with 33% at 15 contact hours and 25% at 10 contact hours. These align well with the three credit hours for most transport courses in the literature [3].

Table 3. Reported contact hours for second-term courses

| Metric | Lab | Lecture | Recitation | Studio |
|---|---|---|---|---|
| Minimum | 15 | 30 | 5 | 1 |
| Median | 33 | 45 | 15 | 16 |
| Mean | 35 | 46 | 16 | 16 |
| Maximum | 60 | 60 | 30 | 30 |
| Mode | #N/A | 45 | 15 | #N/A |
| Count | 4 | 37 | 12 | 2 |

Of the reported contact hours, 15% is spent on momentum transfer, 47% on heat transfer, 28% on mass transfer, 8% on separations, and 2% on other topics, on average. The medians are 50% time on heat transfer and 30% time on mass transfer. The courses could be broken up into the following:

- 4 primarily fluid mechanics courses (60% or more momentum transfer)
- 4 relatively-evenly distributed transport courses (matching the titles above)
- 7 entirely heat transfer courses (matching the course titles above)
- 12 heat transfer and mass transfer courses, ranging from 45% to 80% heat transfer, also matching the titles above
- 1 entirely mass transfer course
- 5 mass transfer and separations courses (60 to 75% mass transfer)
- 5 other.

There are combined transport courses that contain a majority of momentum transfer or heat transfer, but the combination courses that are majority mass transfer are combined with separations instead of another transport.

The four momentum transfer topics that are covered by at least 25% of the second-term courses are boundary layers, pressure drop, velocity profiles, and dimensional analysis. No momentum transport topic is covered by more than a third of these courses. Separations topics are covered in even fewer second-term courses than fluid mechanics topics: only column design, packed bed design, and binary distillation are covered in more than 10% of the courses. No separations topic is covered by more than five courses (13%). The low coverage of these topics is expected given that 75% of course time is spent on heat transfer and mass transfer.

The heat transfer topics covered in the second-term courses are given in Figure 11. Twenty-eight courses listed at least 25% of the course time is spent on heat transfer. The only topics that are not covered by at least 40% of the courses are heat integration/pinch analysis and heat exchanger networks. The "other" topics covered are shape factors/conformal mapping, extended area HT (fins & pins), dimensional analysis with similarity and scaling, and control volume analysis. Heat exchangers are covered in 27 courses, but shell balances are covered in only 16 courses. This indicates about half of the courses use both a transport phenomena approach and a unit operations approach, ~10% use a transport phenomena approach only, and ~40% use a unit operations approach only.

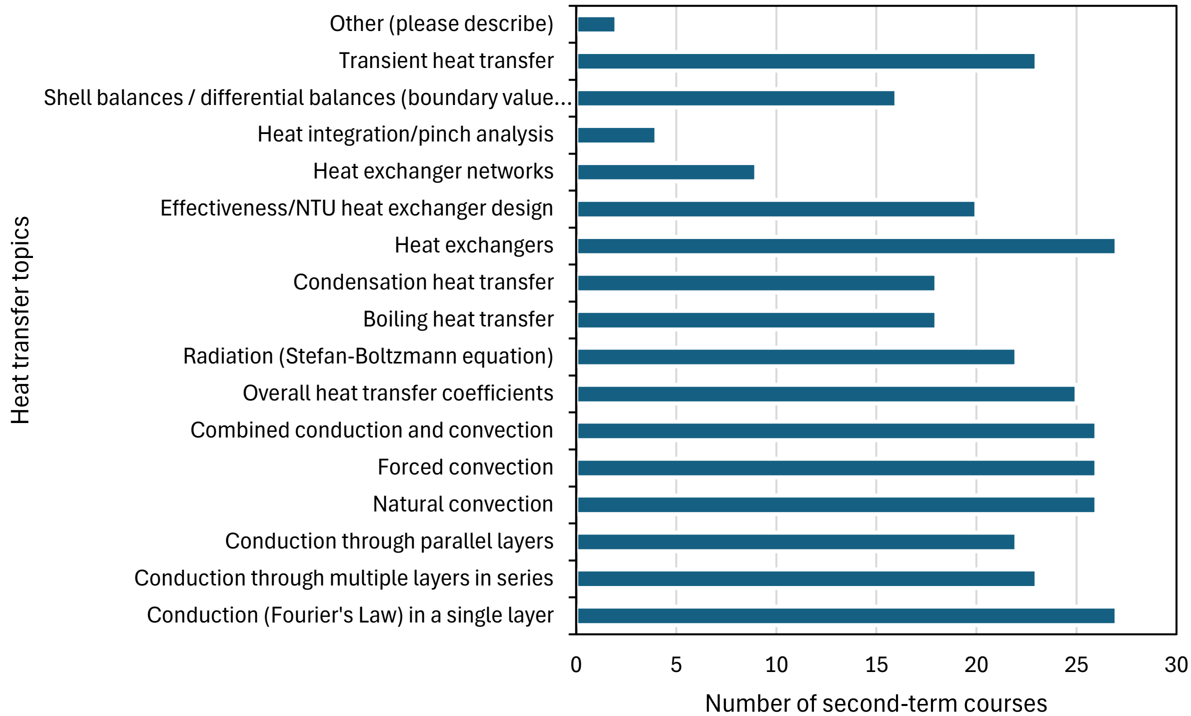


Figure 11. Heat transfer topics covered in second-term courses. N = 38.

Mass transfer topics covered in the second-term transport courses are shown in Figure 12. The highest coverage of a mass transfer topic is diffusive/convective mass transfer in stationary media in 24 courses. Given that the second-term courses spend on average half of the time on mass transfer as they do on heat transfer, it is surprising that the mass transfer topics are covered in only slightly fewer courses than heat transfer topics (averages 17 for mass transfer versus 20 for heat transfer). The topics covered in fewer than 40% of the second-term courses are solubilities, two-film theory, and mass transfer equipment. The “other” topics covered are heterogenous catalysis (Thiele modulus), dimensional analysis, Chilton-Colburn relation, capacity coefficients for packed tower, membrane transport, and ligand-receptor binding. The topic of “mass transfer equipment” was used to assume a unit operations approach to the course, and “mass transfer boundary conditions” was assumed to mean a transport phenomena approach. One course (5%) covers mass transfer equipment but not mass transfer boundary conditions, eight courses cover both (38%), and 12 courses cover only boundary conditions (57%). As with the heat transfer topics, about half of the course use both approaches. Unlike heat transfer, the second-term courses were more likely to use a transport phenomena approach than a unit operations approach. In 2014, both unit ops and transport theory were used in 61% of the second courses, which is about 15% more than seen in 2024.

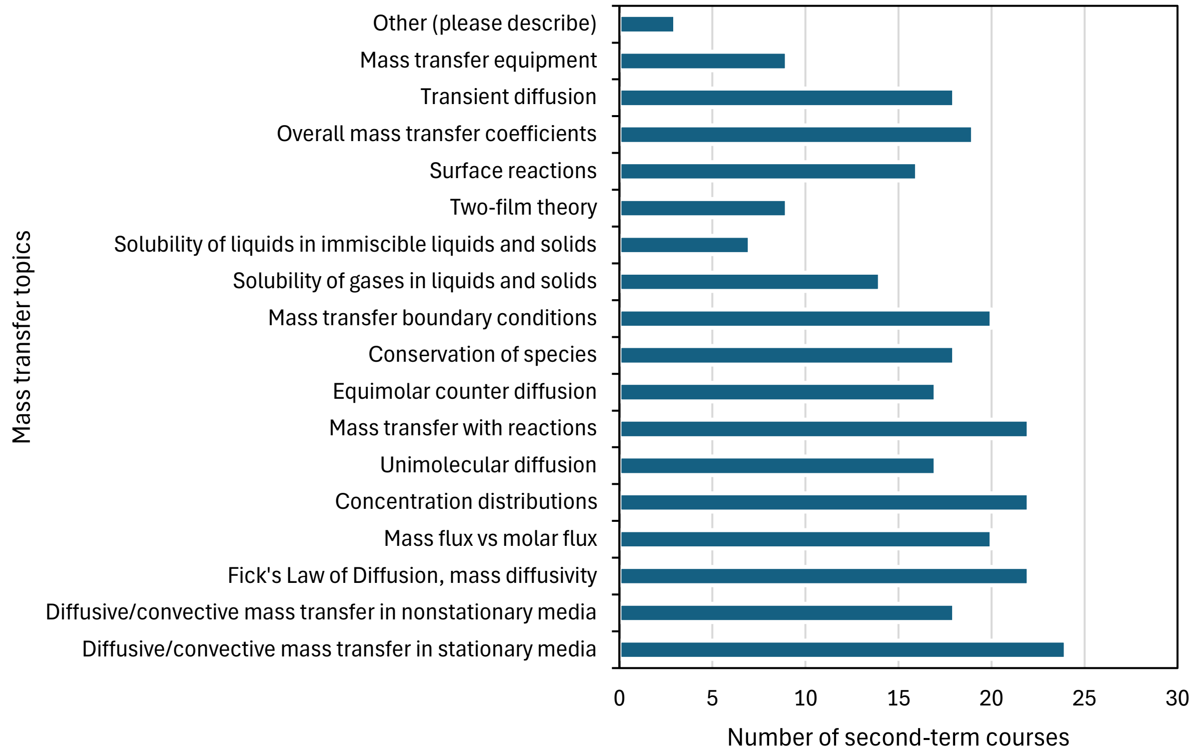


Figure 12. Mass transfer topics in second-term courses. N = 38.

The textbooks used in second-term transport courses are presented in Figure 13. Bergman (co-author Incropera), Welty, and Geankoplis are the most-commonly-used books for this course. Textbooks by these three authors were also the most popular textbooks for the second transport course in 2014.

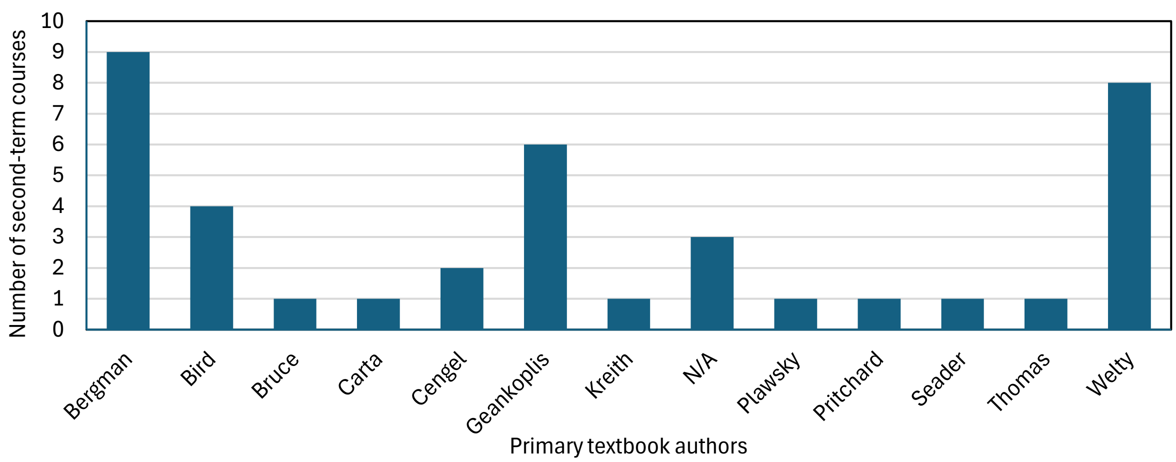


Figure 13. Textbooks used in second-term courses. N = 38.

Computational or software modeling components are included in 68% (25) of the 38 second-term courses. Of those 25 courses, 4% do not include the activities in the course grade, 36% include some of the activities, 20% include most, and 40% include all activities in the course grade. The software packages used are given in Figure 14. Excel and Matlab are the most-commonly used software packages. The “other computational” packages are PIPE-FLO, checalc.com, a CACHE Windows-based module, and online McCabe-Thiele simulator. One faculty member specified MATLAB's Symbolic Toolbox and ODE & PDE Toolbox. The “other simulation” software is Aspen Energy Analyzer for heat exchanger networks, and another course has used PetroSkills and CHEMCAD in the past but didn’t this particular semester.

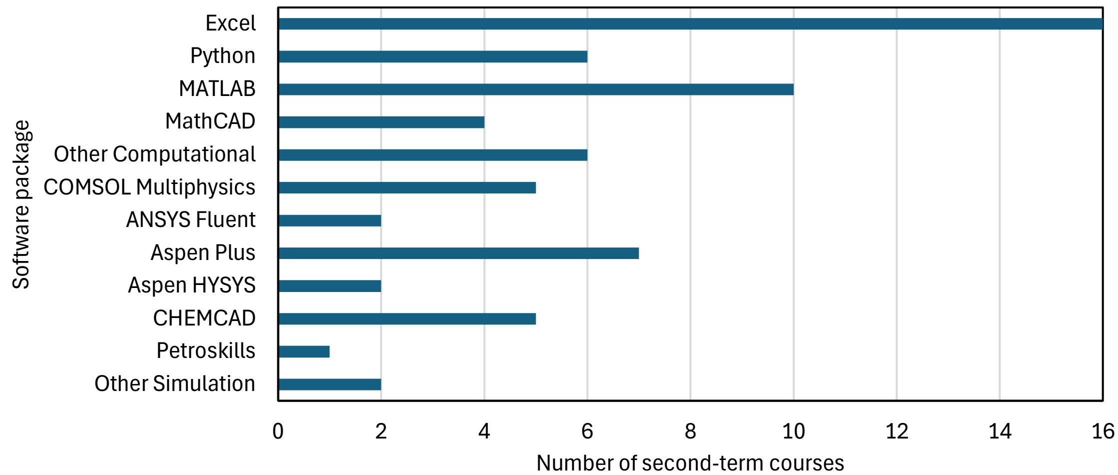


Figure 14. Computational software used in second-term courses. N = 25.

Only 37% (14 courses) of the 37 responding second-term courses use non-computational experiential activities. None of those activities count toward the course grade in 50% of the courses; some, 14%, most, 0%, and all, 36%. In those 14 courses, instructor demonstration of equipment (64%) and bench-scale student-led experiments (57%) are the most common. Pilot-plant-scale student-led experiments are in only 21% of the courses, and plant tours are used in 14%. In one course, the students analyze the configuration of small display heat exchangers.

Third-term Transport Course: (Heat and) Mass Transfer

We received information about nine courses in the transport series that are taught in the third term. All of these courses are disciplinary courses. Four of these courses include Heat and Mass Transfer in the title, three include only Mass Transfer, one course is Unit Operations Design, and one is Separations Processes. Seven of the nine (78%) are primarily taken in the junior year, and the remaining two (Unit Operations Design and Separations Processes) are taken in the senior year. This timing matches the junior timing reported by [4]. Seven of these courses meet for 45 contact hours during the term. One meets for 42 contact hours, and one mass transfer course is only 30 contact hours, agreeing with [3] for credit hours. Textbooks by Geankoplis and Incropera are used by two courses each, and textbooks by Middleman, Towler, Wankat, and Welty are used by one course each.

As indicated by the course titles, the content of these third-term courses is primarily heat transfer and mass transfer. The course time is spent on 3% fluid mechanics, 33% heat transfer, 47% mass transfer, 16% separations, and 1% other on average, but there were clearly three different types of courses offered in the third term. The four courses with Heat and Mass Transfer in the title spend 50% or more of time on heat transfer with an average of 28% on mass transfer. Two of the “Mass Transfer” courses spend 85% or more of the time on mass transfer, but one “Mass

Transfer" course is evenly split between mass transfer and separations. The other two third-term courses are 40% separations with one course dividing the remaining time over heat transfer and mass transfer and the other adding in fluid mechanics and other topics.

As mentioned earlier, only 3% of course time on average is spent on fluid mechanics. Velocity profiles, dimensional analysis, and boundary layers are the only topics covered by three or more of the nine courses. The coverage of heat transfer topics in these third term courses is given in Figure 15. Only 33% of course time on average is spent on heat transfer topics, but 10 of the 14 topics are covered in at least half of these courses. Overall heat transfer coefficients, natural convection, forced convection, and combined conduction & convection are the topics covered in the most courses. There are many fewer topics listed here than in Figure 11 for the second-term courses – the missing topics are not covered in any of the third-term courses.

Figure 16 presents the coverage of mass transfer topics in the third-term courses. Remember that seven of the nine (78%) third-term courses have "Mass Transfer" in the title, and 47% of the course time on average is spent on mass transfer topics. None of the mass transfer topics is covered in all nine of the courses, but nine of the 16 topics are covered in seven or more of the courses. Reactions, both at the surface and with mass transfer, are the topics least likely to be covered. Seven of the nine (78%) courses discuss both boundary conditions, which are necessary for a transport theory approach to the course, and mass transfer equipment, indicating a unit operations approach to the course.

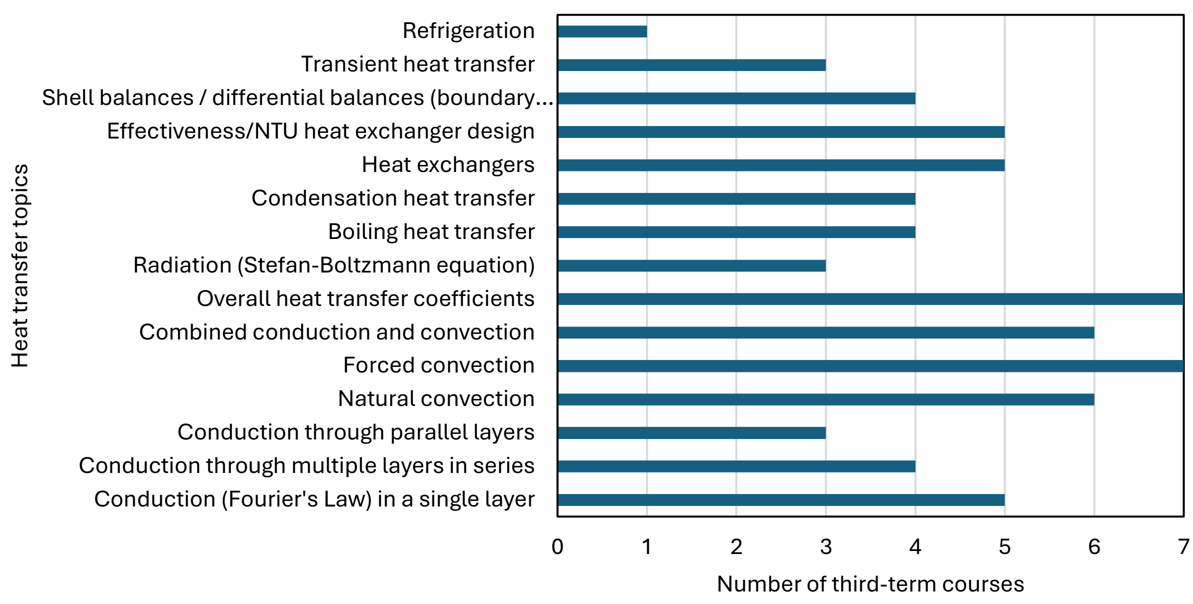


Figure 15. Coverage of heat transfer topics in the third-term courses. N = 9.

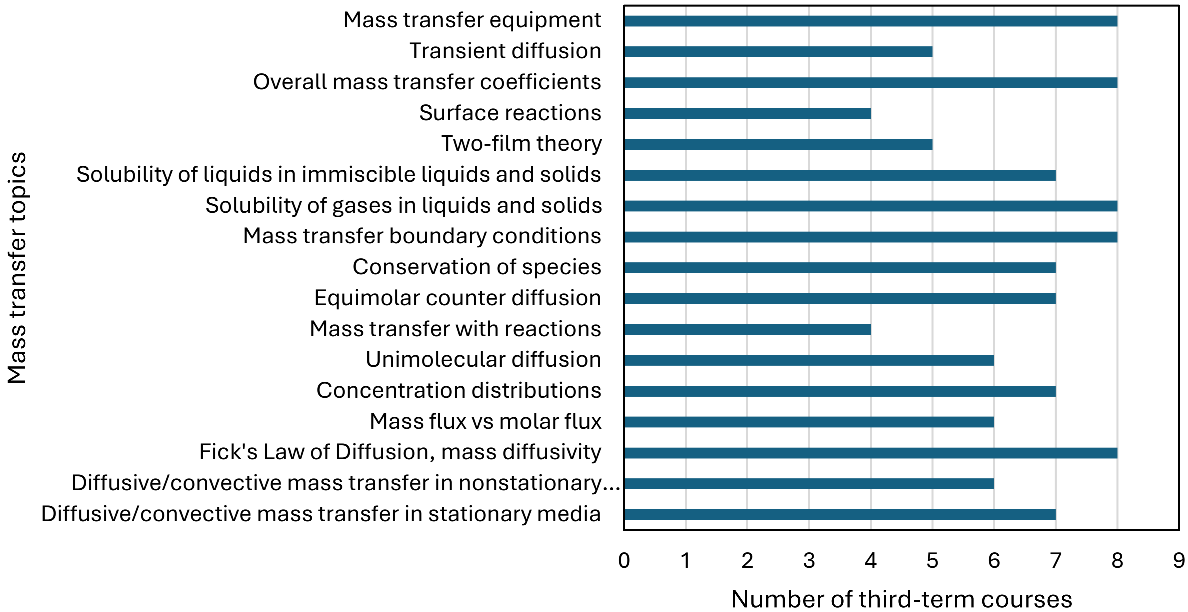


Figure 16. Coverage of mass transfer topics in third term courses. N = 9.

Sixteen percent of the course time for third-term courses is spent on separations, and this is reflected in the lower coverage of the separations topics than heat transfer and mass transfer topics. Only six topics are covered in three or more of the courses: packed bed design, membrane separation processes, liquid-liquid extraction, column design, binary column distillation, and absorption & stripping. The topic covered in the most courses, seven of nine, is absorption & stripping.

Two-thirds of the nine third-term courses incorporate computational or software modeling components. All of the computational/modeling work is included in the course grade for a third of the courses, most for 17% of the courses, and some for half of the courses. Aspen Plus and Matlab are used in half of the courses with this component, Python is used in a third of the courses, and Aspen HYSYS and COMSOL Multiphysics are used in 17%.

Most of the third-term courses do not use non-computational activities: seven of nine. One course uses bench-scale experiments for a grade. The other course uses instructor demonstrations of equipment for no grade.

There are many similarities to the 3rd courses in the 2014 survey, which were primarily mass transfer with separations. 83% of those courses had "mass transfer" in the title, and 91% were offered in the junior or senior year. Geankoplis and Seader were the two most common primary authors in 2014. Geankoplis remained as a top book, but Seader was not mentioned for this course in 2024. That roughly 75% of the courses take both transport theory and unit operations approaches to the course is unchanged.

"Other" Term Courses

We received information about six courses that we categorized into a term "Other". These courses do not fall into the series of transport courses yet contain transport topics or are a fourth-term course. "Heat Transfer" and "Mass Transfer" appear in the titles for two courses each. These courses usually have 45 contact hours in lecture, but one course has 48 contact hours evenly split between lecture and studio. These courses are all in the junior or senior year. In one course, all of the time is spent on heat transfer, and another is solely mass transfer. One course is a thermodynamics course with 40% separations. The other three courses divide their time among the four topics: 30% fluids, 20% heat transfer, 10% mass transfer, and 30% separations on average.

Given the wide range of course topics, it is not surprising that a distinct textbook is used in each course. The course topics covered are also not uniformly covered. The topics covered by half or more of these "other"-term courses are energy and Bernoulli balances, pressure drop, combined conduction & convection, overall heat transfer coefficients, heat exchangers, effectiveness/NTU heat exchanger design, Fick's law of diffusion, two-film theory, overall mass transfer coefficients, mass transfer equipment, and absorption & stripping. These are applications or unit operations courses, as indicated by the topics in previous sentence and that shell balances for heat transfer and boundary conditions for mass transfer are covered in only one course each.

Two-thirds of the courses include computational or software modeling in the course, with some of the activities counting toward the course grade. Excel and Python are the only packages used in three or more courses. None of these courses has non-computational experiences.

Non-computational Experiential Activities – All Courses

Thirty of the respondents gave at least one answer to the prompt "Please briefly describe your non-computational experiential activities." Some responses contained more than one theme and thus resulted in multiple codes for the response, while others did not result in a code being applied.

Of these 30 responses, 15 responses were coded with the theme "In-Class Demo" – this code was applied when the response described experiences where instructors performed a relevant demonstration or "show-and-tell" in front of the class; examples include:

- Instructor demonstrations for topics include: Surface tension, Torricelli's Law, Non-newtonian fluids, incline flow or Bingham fluid, Stokes Law, Magnus Effect. Students investigate capillary flow of viscous liquids during in-class activity. Student assignment is to choose one of the in-class demos and expand upon the concept by conducting an independent experiment outside of class and preparing a report on findings.
- We also have show and tell with old heat exchangers, pipe fittings.
- We have a valve demo (cut-aways of the many different types of valves).

Thirteen responses were coded with the theme of "Laboratory" – this code was applied when the response mentioned experiential activities involving students completing experimentation in (what appears) to be a formal laboratory environment. Representative comments included:

- We have lab-based activities that cover rheology, agitation and mixing time, pressure drop across packed beds and venturi/orifice meters, fluidized beds, drag coefficients/external flow.
- Students perform 4 experiments throughout the semester, working in groups of around 3. Afterwards, a written lab report is submitted by the group.
- Lab on conduction through slabs, lab on heat exchangers

Three responses were coded with the theme “Desktop Modules” – this code was applied when the response mentioned student experimentation in the classroom (rather than a laboratory) using desktop modules:

- Small desktop module activities demonstrating pressures in a venturi meter and application of the Bernoulli equation.
- Another day they used the desktop learning module for pressure drop. The data analysis and discussion for these counted as homework.”

Finally, two responses were coded with the theme “Facility Tour” – this code was applied when the response indicated that a field trip to a facility tour was to complement classroom instruction:

- The students also tour a local ag processing facility to grasp the size of unit operations.
- We have also visited the university steam plant. Students get to see many different types of heat exchange equipment and some water treatment equipment like ion exchange beds and water softeners.

Novel or Distinctive Pedagogical Features – All Courses

Fifty-seven of the respondents gave at least one answer to the prompt “Please describe any novel or distinctive pedagogical features of your transport and/or separations course or your department's transport course series.” Some responses contained more than one theme and thus resulted in multiple codes for the response, while others did not result in a code being applied.

Eleven responses were coded with the theme “Hands-on / Laboratory Experiences” – this code was applied when the response described students interacting with course content in a hands-on environment; examples include:

- The fluids course aims to be hands-on in the lab to supplement lecture material. A simple design project (piping system related) is also included.
- We try to make this introduction to transport very practical and relevant to the real world. Examples are tied to everyday phenomena and when given the opportunity, hands on demos and videos are used.

Ten were coded with the theme of “Design / Project-Based Learning” – this code was applied when the response stated that student projects (some of which may have involved design) were used to complement classroom instruction and assignments. Representative comments included:

- We have a team design project in our fluid mechanics class, in which students work together to design the piping, valving, pumps, flow meters, kettles, heat exchangers, and extruder unit operations for an industrial process.
- We also include a project on surveying, reporting, and explaining fluid mechanics phenomena in an accessible manner to a broad audience.

Eight responses were coded with the theme “Flipped Classroom” – this code was applied when the response mentioned the flipped classroom practice:

- Often taught in a flipped/hybrid mode (3 lectures asynchronous on-line, one two-hour discussion session each week).
- Course is taught with a flipped classroom design

Six responses had an emergent theme of “Computational Tools” which was applied when a response mentioned the use of computational tools to complement course content, as exemplified by the following:

- Use of ANSYS FLUENT, discussion of numerical methods using Excel to solve first order ODEs and BVP, case study on radiative transfer to teach global warming
- We have a focus on using computational tools (Excel, Python, and ProMax) and have modules that we do in a "flipped" manner, where students watch a video demonstration on the technique outside of class, but then bring their laptops to class to actually do the computational modules.

Another six responses specifically mentioned that group work on problems or projects was incorporated into the course, yielding the code “Group Work”:

- My course typically features a substantial emphasis on in-class problem solving in small groups and on concept questions
- Group assignments, meet with each group biweekly to discuss homework problems

One response was coded as “Safety Content” specifically referenced the inclusion of process safety, an ABET requirement for ChE curricula, into transport course content:

- “Te students complete a design project. Safety considerations have been a requirement for these design projects recently.

Four responses were assigned “Nothing Novel” which applied when the response acknowledged that the respondent felt their instruction was not particularly novel or described a “typical” teaching approach, such as:

- Not much novel.
- Students are asked to read assigned chapter before coming to lectures.

Finally, there were also five novel and distinctive responses which didn’t fit into any of the previously-mentioned themes, which were categorized as “Other”, including:

- This course has a 20-hour Studio plan. The primary objectives of the Studio plan are Teamwork, Gender equity, and leadership.
- Use of symbolic math for every problem solution.

Challenges in Teaching Transport Phenomena and Applications – All Courses

Sixty-one of the respondents gave at least one answer to the question “What do you find particularly challenging about teaching this transport and/or separations course?” A common theme in the responses was time constraints and volume of material. 16 respondents who identified their courses as “primarily transport” and four who identified their courses as “transport/separations mix” gave answers in this vein.  Representative comments include:

- The amount of content in this class is a bit overwhelming. We do our best to cover as many topics as possible in an appropriate amount of depth.
- There is a tremendous amount of relevant content across heat and mass transfer, and so we need to make decisions about depth and breadth in the topics covered.
- Too much material for one semester even in a 4-credit course.
- Fitting in all the material that I want to cover. Mass transfer is enough for one semester, but we squeeze in equilibrium staged separations, too.
- There is a tremendous amount of relevant content across heat and mass transfer, and so we need to make decisions about depth and breadth in the topics covered.

Nineteen respondents mentioned student skills, preparedness, and/or retention from previous courses as a challenge.  Of these 14 specifically mentioned math skills as a challenge:

- It is the first course which requires students to apply math to physical problems.  Students are required to build upon concepts which they already learned a year before.
- A lot of students do not know how to apply mathematical methods to solve differential equations
- Students are not always prepared for the mathematical requirements of the course.
- Math is always challenging to students. So, a review of pre-requisite calculus and Diff. Eq. helps.

Other aspects of student preparedness that were highlighted included:

- Students background from previous courses specially in Mass Transport.
- Heat Flow has a lot of content and depends heavily in the knowledge of Fluid Dynamics. Some students struggle because they don't understand fluids well.
- Lack of programming/Python skills.
- Students lack the basic problem-solving aptitudes that could be expected 30-50 yrs ago (alright boomer...)

Seven respondents commented on a challenge that was associated with a specific topic within the course:

- The hardest topics for students are macroscopic force balances and compressible flow.
- liquid vapor equilibrium (connected with identifying boundary conditions)
- Compressible flow is challenging for the students.
- Rigorous derivations on velocity profiles and Navier Stokes
- 3-dimensional perspective (use of tensors, double integrals) is also challenging to for the students to grasp.
- Students really struggle with the Bernoulli equation when first introduced at the beginning of the semester. I've found that letting them redo the first exam for additional points has improved their confidence and skills when solving energy balances.
- finding problems/examples with biomedical applications

Six respondents identified challenges related to the abstractness of the material, and/or relating theoretical models to physical realities:

- I would love to incorporate more "non-computational" exercises, especially to reinforce physical understanding, but these are expensive and time-consuming to design and implement.
- Mass transfer is in particular a difficult subject, and the lack of "tangible" experiences of this transport phenomenon does seem to be a problem.
- For fluid mechanics, trying to find the right balance of practical/applied fluid mechanics (friction in piping systems, designing systems, pumps, etc.) vs. more theoretical, differential analyses (Navier-Stokes).
- The balance between fundamental principles, and the practical industrial topics, such as pump sizing, etc.
- Not losing the students in derivations, while making sure they understand where terms and models came from.
- The challenge is to build the connection between industrial scale heat transfer with textbook examples.

Three respondents highlighted making connections between topics as a challenge:

- Moreover, students struggle to see the analogies between heat and mass transfer, even mathematically.
- The mass transfer part of the course and the stage-wise operations part of the course feel too distinct from each other and students sometimes have difficulty identifying the connections between them.
- The connections between all transport phenomena while courses are taught separately. For this reason actually we are in a process of developing a new course as heat and mass transfer.

Three respondents mentioned challenges associated with student interest:

- The fluid statics portion of the course seems less applicable and less interesting for the students than the fluid dynamics portion.
- This course is not challenging to teach in terms of the content which is quite easy. There are a lot of empirical correlations for different flow regimes and geometries which can be bland.
- It's sometimes difficult to avoid getting bogged down in dense portions of the materials.

One respondent expressed the inability to find a good book as a challenge, saying “textbooks are poorly-organized, confusing, lack consistent use of units in sample problems.”

Other respondents identified issues that were legitimate challenges but were related to how the course was taught at their institution, or other matters that weren’t necessarily specific to the topic of transport:

- nothing particularly challenging about the topic. PBL is a challenging format.
- A particular challenge is to provide the out-of-class technical and emotional support that students want/need.
- I teach the "off-semester" course, so the distribution of students is always quite bimodal (students who are "ahead" of the typical course schedule and students who are re-taking the course).

- It's the first time students see a real chemE class and they don't realize how much work it requires.
- My students generally struggling with the relative lack of examples and practice problems in class, compared to the 200-level courses (mass and energy balances).
- I am a new assistant professor, and this is my first course to teach. I have a lot to learn.

Comments about Educational Materials – All Courses

We received 94 responses to "What educational materials are currently missing that would help you teach this course better?". The majority, 62%, were "none", "uncertain", or that the faculty were happy with available materials. The largest group of requests (12%) was for plug-and-play software tools or interactive simulation modules. The next largest category, 10%, was a request for more solved problems, case studies, and industrially-relevant problems. Nine percent of the faculty were interested in more hands-on activities, demonstrations, and/or videos. Textbooks were a complaint for 9% of the faculty, including problems with mechanical-engineering-oriented textbooks, the balance between heat and mass transfer, lack of a Zybook for the course, and inexpensive ways of accessing references.

## Conclusions

The responding departments offer an average of 2.4 courses in transport phenomena and applications. These courses are offered primarily in the junior year. The first-term course is typically momentum transfer, although 25% of the first-term courses are transport phenomena courses. The second-term course is heat (and mass) transfer, and the third-term course, if it exists, is (heat and) mass transfer. The use of computational software increases as the students move through the curriculum while the use of non-computational experiences decreases. MATLAB is used at a high rate in all terms, but the use of Excel shifts to the use of Aspen Plus as the students advance. No one textbook dominates the market for any of the terms. Nearly half of the course use both a transport phenomena and a unit operations approach to teaching the material. There have been only small shifts in these courses since the 2014 survey.

## 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 and Exposition*, Seattle, WA, 2015.

[2] AIChE Education Project Committee, "AIChE Education Project Committee Surveys," 6 July 2018. [Online]. Available: https://www.aiche.org/community/sites/divisions-forums/education-division/files/aiche-education-projects-committee-surveys.

[3] R. S. Voronov, S. Basuray, G. Obuskovic, L. Simon, R. B. Barat and E. Bilgili, "Statistical analysis of undergraduate chemical engineering curicula of United States of America universities: Trends and observations," *Education for Chemical Engineers,* vol. 20, pp. 1-10, 2017.

[4] Z. Rasmussen and A. Butterfield, "Curriculum and Teaching Load in Top-Ranked U.S. Chemical Engineering Departments," in *ASEE Annual Conference and Exposition*, Portland, OR, 2024.

[5] Course Survey Committee of AIChE Education Division, "How We Teach Surveys," 2024. [Online]. Available: https://www.aiche.org/community/sites/divisions-forums/education-division/how-we-teach-surveys.

[6] L. P. Ford, J. Brennan, H. Chenette, M. Cooper, K. Dahm, J. Gartner, L. Landherr, D. Silverstein, S. Thiel and T. Vogel, "The Organization of Transport Topics in Chemical Engineering Curricula," in *2024 ASEE Midwest Section Conference*, Lawrence, KS, 2024.

Appendix A: Survey

Q1 Thank you very much for responding to this survey. The AIChE Education Division Survey Committee asks departments yearly about the current state of undergraduate education in a particular area of chemical engineering. This year, we are focusing on required courses in transport phenomena and applications, including equilibrium-based separations. Please have someone in your department complete this survey **for each required course** in transport and applications. Previous recent surveys have been on Electives, Process Safety, Capstone Design, Material & Energy Balances, the First-year Experience, Unit Operations Laboratory, Thermodynamics, Controls, Kinetics and Reactor Design, and the curriculum as a whole. Our collected publications archive is available through this Google drive link. You can view a Google Doc version of this survey at this link. Questions? Please contact Laura Ford (committee chair) at laura-ford@utulsa.edu. Thank you for your help!

Q2 The University of Tulsa Office of Research and Sponsored Programs has determined that this survey is not human subjects research. Qualtrics predicts that this survey will take 9 minutes to complete for each course.

Q3 Please enter the name of your institution. ________________________________________

Q4 Please enter the name of your required course in transport phenomena and/or applications. This survey should be completed once for each required course. _______________

Q5 According to the course description, how many hours of contact time does each component of this course have over the entire term? A 3-credit-hour semester-long lecture course typically has 45 contact hours in lecture.

- ○ Lab ________________________________________________
- ○ Lecture ________________________________________________
- ○ Recitation ________________________________________________
- ○ Studio ________________________________________________
- ○ Other (please name) ________________________________________________

Q6 In which year is this course typically taken?

- ○ First
- ○ Second
- ○ Third
- ○ Fourth
- ○ Fifth

Q7 Is this course part of a series in transport phenomena and applications?

- ○ No
- ○ Yes

Q8 Please describe how this course fits into your transport and applications series. Examples: first course in three-course series, or it and another transport course are taken together in the second term of a three-term series.

________________________________

Q9 Which kind of course is this?

- ○ disciplinary (taken primarily by your majors)
- ○ multi-disciplinary (taken primarily by multiple majors)

Q10 Many courses in transport phenomena contain more than one subject. Please indicate the approximate breakdown of time in your course.
Momentum transfer (Fluid mechanics) : _______
Heat transfer : _______
Mass transfer : _______
Separations (rate- or equilibrium-based) : _______
Other (please describe) : _______
Total : ________

Q11 Please write the last name of the primary author for the primary textbook you use in this course. Write "N/A" if your course does not have a required textbook. ____________________

Q12 The next four questions ask what topics are covered in your transport and/or applications course. Topics are arranged into courses in a wide variety of ways, so please read carefully to catch your specific topics. If your course is narrowly focused and a category does not apply to your course, please select "none of the above".

Q13 Please select all of the topics in momentum transfer (fluid mechanics) that are covered in your course.

- ▢ Fluid properties
- ▢ Hydrostatic pressure
- ▢ Buoyancy
- ▢ Stability
- ▢ Forces on planes
- ▢ Forces on curved surfaces
- ▢ Fluid kinematics
- ▢ Energy and Bernoulli equations
- ▢ Friction
- ▢ Linear momentum
- ▢ Angular momentum
- ▢ Reference states and relative velocities
- ▢ Dimensional analysis
- ▢ Velocity profiles
- ▢ Pressure drop
- ▢ Minor losses
- ▢ Differential analysis of fluid flow (Navier-Stokes equation)
- ▢ Creeping flow
- ▢ Inviscid flow
- ▢ Irrotational flow
- ▢ Boundary layers
- ▢ External flow - drag

- ☐ External flow - lift
- ☐ Compressible flow
- ☐ Open-channel flow
- ☐ Flow around submerged objects
- ☐ Flowrate and velocity measurement
- ☐ Turbomachinery (pump and turbine selection and design)
- ☐ Computational fluid dynamics
- ☐ Flow through porous media
- ☐ Fluidized beds
- ☐ Designing a pipe network
- ☐ Relief device sizing
- ☐ Other (please describe) ________________________________________________
- ☐ None of the above

Q14 Please select all of the topics in heat transfer that are covered in your course.

- ☐ Conduction (Fourier's Law) in a single layer
- ☐ Conduction through multiple layers in series
- ☐ Conduction through parallel layers
- ☐ Natural convection
- ☐ Forced convection
- ☐ Combined conduction and convection
- ☐ Overall heat transfer coefficients
- ☐ Radiation (Stefan-Boltzmann equation)
- ☐ Boiling heat transfer
- ☐ Condensation heat transfer
- ☐ Heat exchangers
- ☐ Effectiveness/NTU heat exchanger design
- ☐ Heat exchanger networks
- ☐ Heat integration/pinch analysis
- ☐ Shell balances / differential balances (boundary value problems)
- ☐ Transient heat transfer
- ☐ Other (please describe) ________________________________________________
- ☐ None of the above

Q15 Please select all of the topics in mass transfer that are covered in your course.

- ☐ Diffusive/convective mass transfer in stationary media
- ☐ Diffusive/convective mass transfer in nonstationary media
- ☐ Fick's Law of Diffusion, mass diffusivity
- ☐ Mass flux vs molar flux
- ☐ Concentration distributions
- ☐ Unimolecular diffusion
- ☐ Mass transfer with reactions
- ☐ Equimolar counter diffusion
- ☐ Conservation of species
- ☐ Mass transfer boundary conditions
- ☐ Solubility of gases in liquids and solids

- ▢ Solubility of liquids in immiscible liquids and solids
- ▢ Two-film theory
- ▢ Surface reactions
- ▢ Overall mass transfer coefficients
- ▢ Transient diffusion
- ▢ Mass transfer equipment
- ▢ Other (please describe) ________________________________________________
- ▢ None of the above

Q16 Please select all of the topics in separations that are covered in your course.

- ▢ Flash distillation
- ▢ Binary column distillation
- ▢ Multicomponent distillation - exact calculation procedures
- ▢ Multicomponent distillation - shortcut methods (e.g., FUG)
- ▢ Binary heterogeneous azeotropic distillation
- ▢ Steam distillation
- ▢ Pressure-swing distillation
- ▢ Extractive distillation
- ▢ More than two outputs
- ▢ More than one input
- ▢ Distillation train design
- ▢ Batch distillation
- ▢ Absorption and stripping
- ▢ Liquid-liquid extraction
- ▢ Washing and leaching
- ▢ Membrane separation processes
- ▢ Packed bed design (HETP and/or HTU/NTU)
- ▢ Adsorption, chromatography, and/or ion exchange
- ▢ Column design (e.g., tray efficiencies, tray hydraulics, flooding calculations, internal designs)
- ▢ Crystallization
- ▢ Filtration, cyclones, settlers, centrifugation
- ▢ Drying
- ▢ Other (please describe) ________________________________________________
- ▢ None of the above

Q17 The next questions are about academic enhancements that you may use in your course.

Q18 Do you incorporate any computational/software modeling components in your course?

- ○ No
- ○ Yes

*Display This Question: If Q18 = Yes*

Q19 Are the computational/software modeling activities part of the students' grades?

- ○ None of them
- ○ Some of them

- ○ Most of them
- ○ All of them

*Display This Question: If Q18 = Yes*
Q20 Which of the following types of software/techniques do the students use? Check all that apply.
- ☐ Microsoft Excel
- ☐ Python
- ☐ MATLAB
- ☐ Mathematica
- ☐ Maple
- ☐ MathCad
- ☐ Other computational software (please specify) ________________________________
- ☐ COMSOL Multiphysics
- ☐ ANSYS Fluent
- ☐ Other finite element analysis software (please specify) __________________________
- ☐ Aspen Plus
- ☐ Aspen HYSYS
- ☐ ChemCad
- ☐ PetroSkills
- ☐ Other process simulation software (please specify) _____________________________

Q21 Do you incorporate any non-computational experiential components (e.g., experimental labs, demonstrations, plant tours) in your course?
- ○ No
- ○ Yes

*Display This Question: If Q21 = Yes*
Q22 Are these non-computational experiential activities part of the students' grades?
- ○ None of them
- ○ Some of them
- ○ Most of them
- ○ All of them

*Display This Question: If Q21 = Yes*
Q23 Which of the following types of activities do you incorporate? Check all that apply.
- ☐ Instructor demonstrations of equipment (bench or pilot scale)
- ☐ Bench scale student-led experiments
- ☐ Pilot scale student-led experiments
- ☐ Plant tour
- ☐ Other (please specify) __________________________________________________

*Display This Question: If Q21 = Yes*
Q24 Please briefly describe your non-computational experiential activities.__________

Q25 This last block has three open-ended questions and a chance to request survey results.

Q26 Please describe any novel or distinctive pedagogical features of your transport and/or separations course or your department's transport course series. ____________________

Q27 What do you find particularly challenging about teaching this transport and/or separations course? ____________________________________________________________________

Q28 What educational materials are currently missing that would help you teach this course better? ____________________________________________________________________

Q29 If you would like to receive the compiled results of this survey, please enter your email address. ____________________________________________________________________

Appendix B: Respondents

The name of each responding university is given. If there was a response for more than one course from the institution, the number of courses is given in parentheses after the name. There were 50 institutions and 94 courses.

Auburn University (2)
Brigham Young University (3)
Bucknell University (2)
California Baptist University (2)
Florida Institute of Technology (2)
Iowa State University (1)
Lafayette College (1)
Massachusetts Institute of Technology (2)
McMaster University (3)
Missouri University of Science & Technology (2)
New Jersey Institute of Technology (2)
New Mexico State University (2)
New York University (1)
North Carolina State University (1)
Ohio University (2)
Oregon State University (2)
Pennsylvania State University (1)
Purdue University (2)
Rowan University (2)
RPI (1)
South Dakota School of Mines and Technology (4)
SUNY Buffalo (1)
Syracuse University (1)
The Cooper Union (2)
The University of Kansas (2)
The University of Texas at San Antonio (1)
Trine University (3)
Tulane University (2)
University of Alabama (1)
University of Arkansas (3)
University of Cincinnati (2)
University of Clemson (1)
University of Connecticut (1)
University of Delaware (2)
University of Florida (1)
University of Houson (2)
University of Massachusetts Amherst (1)
University of Miami (2)
University of Minnesota Duluth (2)
University of New Hampshire (2)
University of North Dakota (2)
University of South Carolina (3)
University of Toronto
University of Tulsa (2)
University of Utah (2)
University of Waterloo (3)
University of Wisconsin - Madison (3)
Vanderbilt University (2)
Washington University in St. Louis (2)
Youngstown State University (2)