A "SECOND-CHANCE" COURSE IN HEAT TRANSFER

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INTRODUCTION

National View

Over the past two decades, there has been considerable effort to increase the pipeline of students who pursue science and engineering majors, with an eye towards increasing economic competitiveness and the quality of life.[1-3] Indeed, these efforts have paid dividends, with the number of engineering bachelor's degrees awarded in the United States increasing from 74,387 in 2009 to 145,618 in 2019.[4] This growth is not poised to last, however, as engineering undergraduate enrollments have peaked and are starting to decline, especially among freshmen.[4]

Another approach, with the potential for near-term yield, is to increase the percentage of students who persist and earn degrees in engineering and other STEM (Science, Technology, Engineering and Mathematics) fields.[5,6] National statistics show that only 33% of the students who enter a college or university as engineering majors in the US graduate in engineering from the same institution within four years, rising to 58% who graduate within six years.[7] Thus, various studies have been undertaken to predict the "success" of entering students based on entry data such as standardized test scores, high-school course selection and grades, extracurricular activities, etc.[6,8] There have also been efforts to correlate certain experiences, such as undergraduate research, with persistence, though the results are often mixed or difficult to interpret due to self-selection of these experiences by students.[9-10]

Local View

This article presents a focused effort to improve student persistence and graduation rates in chemical engineering through a "second-chance" course in heat transfer. At the University of Colorado, heat transfer is taught in the first semester of the third year of the curriculum, following fluid mechanics the prior semester and preceding courses in separations and mass transfer, kinetics and reactor design, and materials the following semester. (Starting in 2020-21, mass transfer is combined with heat transfer rather than with separations.) The heat-transfer course has proven to be particularly difficult, with an overall distribution of 27.0% A, 37.8% B, 23.0% C, and 12.2% D or F grades (including + and – grades) over the past three years with different sets of instructors For comparison, other key junior courses (thermodynamics, separations, and kinetics) have a combined overall distribution of 27.6% A, 40.0% B, 29.2% C, and 3.2% D or F over the past three years. Since a grade of C- or better is required to move on to the next courses in the curriculum, and we offer the upper-division courses only one semester per year, the students receiving D or F grades are faced with a one-year delay or a difficult decision to change majors or leave the university.

As a potential solution to this dilemma, we created a second-chance course in heat transfer, which has been taught each January starting in 2018. We now refer to it as an "intensive" course in heat transfer, as it may be useful to other students, such as those who took a heat-transfer course while on study abroad or at a different institution (see the next section).

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The concept was introduced in a recent *AIChE Journal* perspective,[11] while the course structure and outcomes are described in more detail in the current article.

COURSE DESCRIPTION

The intensive course in heat transfer takes place during the first 3.5 weeks of January. It has a hybrid on-line/in-person structure, with these two components in series rather than in parallel (the latter has been common for regular courses during the COVID-19 pandemic). Students take the on-line portion during the latter part of the winter break and the in-person portion starting the weekend before the second (spring) semester starts. We do not have a January term, so officially the course is part of a special session of the spring semester. However, students complete the course and grades are tabulated by midway through the second week of the semester. In that way, the intensive workload does not interfere very much with the students' regular courses in the spring semester, and they know the outcome before the drop/add deadline.

The intensive course is a stand-alone course only in the sense that it provides comprehensive coverage of the major themes of heat transfer and the grade is based solely on work done during the intensive course and not the previous course. However, the pace is fast, and it is assumed that students attempted a prior course and so have familiarity with the subject. All students in the first three offerings of the intensive course had taken our regular heat-transfer course the semester before, receiving a grade of D or F. Additionally, about 10% of our undergraduates study abroad in the first semester of their junior year, and the heat-transfer courses available to them at the host institutions often do not have the depth of our course in one or more of the key areas (conduction, convection, radiation, heat exchangers). Thus, we intend to make the intensive course available to these students on a modular basis when they return. (Unfortunately, this application will need to wait at least a year, as study-abroad programs for Fall 2020 were cancelled due to the COVID-19 pandemic.) On a less-frequent basis, transfer students or current students who are out of sequence petition us to accept a heat-transfer course from another institution. When it is not from an accredited chemical engineering program, the coverage of certain topics is often inadequate; the intensive course will allow us to accept the transfer course in tandem with taking certain modules of the intensive course (as was done in January 2021 for the first time).

Neither the regular course nor the intensive course includes a laboratory component, as there is a separate chemical engineering laboratory course in the senior year. The regular course includes a heat-transfer project with computer simulations; the intensive course does not have a project, but computer or spreadsheet solutions are required for some homework problems in both versions of the course.

On-line Portion

The on-line portion of the intensive course officially starts on or near January 1st, but the students are granted access to the materials several days earlier. It includes the following components:

1. ***Prior-semester course materials:*** All lectures, videos, homeworks, exams, solutions, and other materials from the prior semester are made available to the students via the Canvas® network portal for the course. Students review these materials at their own pace and as needed for the homework assignments.
2. ***Screencasts with embedded quizzes:*** The website for LearnChemE© has dozens of publicly available screencasts on heat transfer, which the students are encouraged to review (www.learncheme.com/screencasts/heat-transfer).[12] To further motivate student learning, we added short required quizzes to 23 of the screencast videos, distributed among seven modules (see Table 1). Each screencast is typically 5-10 minutes in length and contains 2-5 embedded quizzes that the viewer must take to proceed with the screencast. For most of these screencasts, a thought question was added at the end for the students to further explore the subject. The screencasts are available via the Canvas portal for the students to view at any time, but we also publish a schedule listing milestone dates by which each screencast and its quizzes should be completed to stay on pace with the homework assignments. The screencasts with quizzes are available at www.learncheme.com/screencasts/heat-transfer/heat-transfer-quiz-screencasts.[12]
3. ***Homework:*** We assigned three or four homework sets associated with the on-line portion of the course, due at midnight each Tuesday and Friday, with the last assignment due as the in-person portion of the course was starting. Rather than using auto-graded problems from the book publisher, we provided original problems to enhance learning and to provide partial credit. The students completed them on paper and then scanned (using cell phones) their solutions and submitted them via Gradescope™.
4. ***Office Hours***: Office hours were held remotely via Zoom® the two evenings before each homework set was due. Typically, the instructor would consider the problems one at a time, discussing the basic concept and approach, and take questions via the chat feature. The instructor or teaching assistant used a tablet for writing and shared the screen. Nearly all of the students participated synchronously in office hours. An interactive and active-learning community was encouraged to promote effective learning.[13-15]

As seen in Table 1, the on-line portion of the course includes the major topics of a chemical engineering course in heat transfer, though the subtopics covered are not comprehensive. The in-person portion of the course also reviews the major topics, though with different emphasis and examples, to provide reinforced and thorough learning.

TABLE 1
On-line Screencast Modules and Subjects

Module	Subject
Heat-transfer Basics	Parameters and Units
	Steady Heat Conduction in a Plane Wall
	Thermal Boundary Conditions
Steady-state Conduction	Thermal Circuits
	Radial Heat Conduction through a Cylindrical Wall
	Conduction through a Spherical Wall
	One-dimensional Heat Conduction with Generation
Transient Conduction	Transient Heating/Cooling with Lumped Capacitance
	Transient Heating/Cooling without Lumped Capacitance
Convection	Thermal Boundary Layers
	Local and Average Heat-transfer Coefficients
	Solving Convection Problems
	Introduction to Free Convection
Boiling and Condensation	Nucleate Pool Boiling
	Film Pool Boiling
Heat Exchangers	Log-mean Temperature Difference
	NTU Effectiveness Method
	Overall Heat-transfer Coefficient
	Saturated Steam
Radiation	Properties of Radiative Heat Transfer
	Net Radiative Heat Transfer Rate from a Surface
	View Factors
	Radiation Exchange Between Surfaces

In-Person Portion

The in-person portion of the course had four review sessions of two hours each held on weekends and late afternoons over a ten-day period at the start of the spring semester. An outline of these reviews is provided in Table 2. In addition, it included one or two homework sets, a graded practice exam, office hours, and a final exam. Teaching assistants helped with the office hours and grading. Students were encouraged to first do the homework and practice exam on their own, but then to seek help if (when) they got stuck. Since the class size was small (varying from 7 to 16 students over the first four offerings), a sense of community and rapport was established.

With only eight hours of lectures (extended to ten hours in 2021), the review sessions cover only key concepts and so rely on the students having previously taken a course in heat transfer and reviewing the prior-semester materials on their own. Some of the subtopics included in the full course but not in the intensive course are condensation (except condensation is included in heat-exchanger design), extended surfaces (fins), two-dimensional and three-dimensional heat conduction, and insulation design (except resistances of insulation layers is covered).

RESULTS AND DISCUSSION

A total of 37 students took the second-chance course in heat transfer over the first three years. One of these students withdrew (when faced with a D grade) while the remainder (97.3%) passed with grades of C- or better. Specifically, the 37 enrollees earned 5 A's, 18 B's, 13 C's and one W in the course (totals include + and – grades). Since taking the intensive course, 23 of these students have graduated with a degree in chemical engineering (or chemical and biological engineering), 12 are still pursuing their degrees in our department (including the one who withdrew from the course, and is now a year behind), one changed majors, and one was discontinued from the university. (The course was offered for the fourth time in January 2021, with screencasts and modules on mass transfer added; there were 1 A, 2 B's and 5 C's earned by the eight students completing the second-chance course after receiving D or F grades in the regular course.)

Besides passing the course with a grade of C- or better, we consider two other performance indicators. The first involves scores on the final exams, which were comprehensive over the entire content for both the regular course and the intensive course. The average score on the final exams in the intensive course was 76% for the 2018-2021 offerings, whereas the average score of the same 45 students on the final exam in the regular course was only 43% (versus 71% for the other students in the regular course). While the final exams in the two versions of the course differed and there was not another control group taking both exams, the improvement in scores is substantial. Indeed, every one of the students (including the

TABLE 2 Outline of In-person Review Sessions	
Session	**Content**
#1	1. Course Schedule and Overview 2. Heat-transfer Overview a. Heat-transfer mechanisms b. Importance in chemical engineering 3. Review of Heat Conduction a. Fourier's law b. Microscopic energy balance c. 1D conduction with and without generation d. Transient heat conduction e. Scaling and order-of-magnitude analysis
#2	4. Review of Forced Convection a. Microscopic energy balance b. Heat-transfer coefficient and scaling analysis c. Boundary-layer heat transfer from a plate d. Internal heat convection in a table e. Turbulence and forced-convection correlations 5. Review of Free Convection a. Boussinesq approximation b. Scaling and order-of-magnitude analysis c. Correlations for free convection 6. Review of Heat Radiation a. Basic principles and types of surfaces b. Emission from a surface/body c. Radiant energy exchange between surfaces
#3	7. Heat Exchangers a. Analysis of a single-tube heat exchanger b. Analysis of a double-tube heat exchanger c. LMTD method for heat-exchangers d. Effectiveness-NTU method for heat exchangers
#4	8. Review for Final Exam a. Exam format and expectations b. How to prepare for the exam c. Review of practice exam and key homework

one not passing the intensive course) achieved an improved score on the final exam of the intensive course. The second additional performance indicator is composed of student grades in subsequent courses that employ, in part, concepts from heat transfer.

We tracked the performance of the students from the first three offerings of the intensive course in the seven subsequent required core courses (separations, kinetics, materials, senior lab, process synthesis, process design, and process control). In total, these students have taken 211 subsequent core courses, resulting in 205 (97.2%) grades of C- or better. Figure 1 shows a bar chart comparing the composite grades of the "second-chance" students in the subsequent core courses to the entire class over the same period.

The overall distribution has primarily A and B grades (85% of all grades), whereas the distribution for second-chance students is shifted toward B and C grades (74% of their grades). The percentage of D, F and W grades is slightly lower for all students (2.1%) compared to the second-chance students (2.8%). The second-chance students are included in the overall distribution and represent 7.2% of the total number of the enrollments in subsequent core courses. As a side comment, the large percentage of A grades is dominated by two senior courses: senior lab (64% A grades) and process design (85% A). The junior-level courses tend to have B grades as the mode, with fewer A grades than C or lower grades.

CONCLUDING REMARKS

The short story is that the intensive course in heat transfer for students in need of a second chance has been a great success. Of the forty-five students who took the course over the first four years, all but one passed and all but two have graduated from or are still enrolled in our chemical engineering program. Without this opportunity, these students would have been delayed one year or left the program.

We are considering expanding the concept to other third-year courses (e.g. separations, thermodynamics, kinetics and reactor design). However, the pass rates in those courses have been higher, and the time investment for faculty is large. We estimate that about 120 person-hours were needed for course preparation and delivery the first time, decreasing to about 60 person-hours after it was established.[11] We are also considering the concept for second-year courses, such as material and energy balances (MEB) and fluid mechanics. Although these courses have substantial numbers of students who do not achieve the necessary prerequisite grades, they do have other options to stay on track. MEB is offered fall, spring, and summer, while fluids is offered spring and summer. As mentioned earlier, the modular design also allows transfer and study-abroad students to take a portion of an intensive course to make up a deficiency in the content of a course taken elsewhere.

Finally, we chose the intensive, second-chance course to be a separate, full-credit course. Students must enroll in the course and pay tuition; the grades are based solely on work performed in the intensive course, and it and the original course and grades achieved have separate entries on

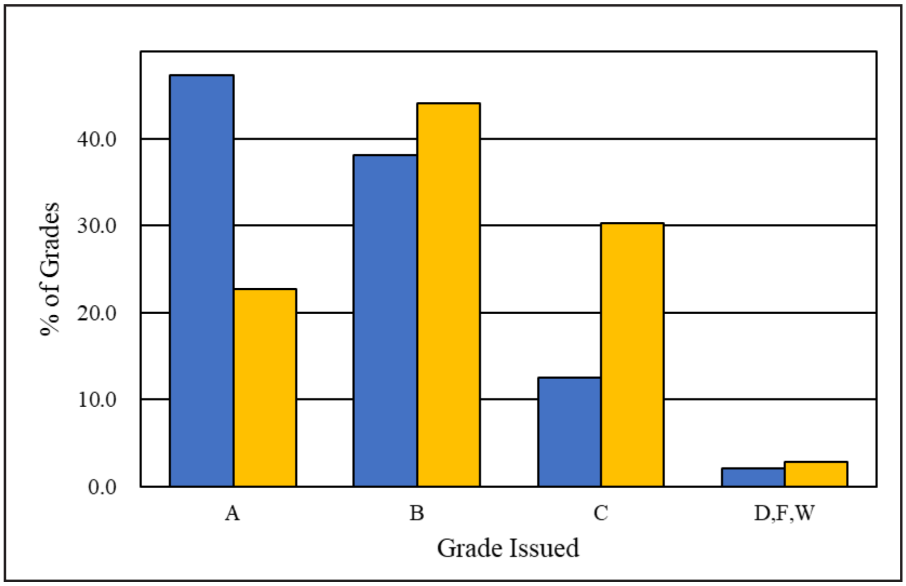

Figure 1. *Combined grade distribution for seven chemical engineering courses following heat transfer. The blue (dark, for print) bars are for all students (530 students, 2936 course enrollments), while the tan (light, for print) bars are for students who took the intensive course in heat transfer in 2018 – 2020 after receiving a D or F grade in the regular course (37 students, 211 course enrollments). The + and – grades are included in each category.*

a student's transcript. An alternative model would be for the second-chance course to be a mulligan or "do-over", where the students take a replacement final exam, after an intensive period of study, and then a change of grade is issued (if warranted) for the original course. We chose the first route, in part so that the students were given a clean slate in earning a grade for the course and in part because we feel it engenders a greater commitment for the students to learn the material.

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