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Establishing Consistent Evaluation Metrics to Combat Pre-Requisite Deficits in Entry-Level Mechanical Engineering Courses

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Abstract

In the aftermath of emergency online instruction, significant faculty turnover, and departmental restructuring, this university has faced challenges in maintaining appropriate, consistent instruction in some pre-requisite, entry-level mechanical engineering courses. This is most clearly seen in the Thermodynamics I to Thermodynamics II sequence. At this university, Thermodynamics I is a multi-section course, and has had varied instructors, including GTA instructors, over the past several semesters. Despite strict requirements for adherence to ABET course topics and student outcome assessment, student experience and learning comprehension continues to have significant variation between sections. This is readily observed in the Thermodynamics II course, as it typically only has a single course section and has been consistently taught by the same instructor over several semesters. In this study, the authors examine the factors contributing to the deficit comprehension, obstacles to addressing the deficit, and the proposed solutions to combatting the pre-requisite instruction/comprehension deficit.

Keywords

Thermodynamics, Mechanical Engineering, Course consistency.

Introduction

While there are several new pedagogy strategies beneficial to student learning environments that are likely to shape the landscape of post-pandemic education[1], in the aftermath of post-2020 emergency online Covid procedures, significant gaps in pre-requisite comprehension have been noted throughout the department. In particular, student performance in face-to-face classes, particularly upper-level courses in the mechanical engineering program, has been reported by seasoned faculty to be well below pre-2020 expectations and norms. It is a known phenomenon that Covid-19 procedures have greatly impacted student performance, even well into face-to-face instruction in 2022. Jonathan Malesic details this in the New York Times guest essay "My students are not ok," in which he discusses dwindling student performance and the perpetuation of poor study habits generated during the online years[2]. Keshvarz points out that one of several shortcomings of total online education includes the lack of discipline and inefficient time usage[3], which compliments Malesic's viewpoint on the development of bad habits. However, the instructors in this department have noticed a deeper issue that became apparent through Covid-19 and post-Covid-19 instruction: a lack of quality control in terms of course consistency and student retention of knowledge. While course consistency is always an obstacle for universities that employ multiple instructors across multiple sections of courses[4], a perfect storm of Covid-19 emergency protocols, significant faculty turnover (including at the departmental leadership level), and departmental restructuring and reorienting toward different learning objectives has left a severe deficit in student pre-requisite knowledge that can be readily seen by veteran instructors. In this paper, we will discuss strategies for improving this consistency as well as review results of student performance across multiple sections of courses.

Methodology

In addition to pandemic instruction, other factors that contribute to lower conceptual retention/subsequent course performance are prevalent due to inconsistency of instruction and a lack of coaching/training for new instructors/GTAs. These factors include instructor engagement with students, instructor/GTA comfort level with material, and differences in educational philosophy. While some instructors focus primarily on an understanding and application of fundamental theory, others focus primarily on working examples and may be less adept at explaining the theory through the examples, instead focusing nearly exclusively on the mathematics without addressing the reasoning behind the math. Many of these factors are due to GTA/first-time instructors having minimal guidance, and others may be brought forward due to motivation for higher evaluations (by providing simply plug and chug style problems)[5]. Therefore, the influences of stronger course mentorship and of uniform testing and homework, removing the ability for instructor to simply make test problems exactly like the homework problems, are examined in this initial exploration of the topic.

Since Thermodynamics I is the initial course in the thermal fluids sequence of Thermo I, Thermo II, Heat Transfer, and Energy Systems Design (ESD) at this university, the focus of this paper is on identifying issues in Thermo I and looking at subsequent performance across later courses. At this University, Thermo I is a pre-requisite for both Thermo II and Heat Transfer, while Heat Transfer is a pre-requisite for ESD. Thus, students may take Heat Transfer and Thermo II simultaneously, though the suggested route is to take Thermo I in the 4th semester, Thermo II in the 5th semester, and Heat Transfer in the 6th semester. Students typically take ESD in the 7th or 8th (final) semester. Throughout 2020 until Spring 2022, Thermo I was relatively un-monitored, with multiple professors and multiple TAs teaching various sections. However, in the Spring 2022 semester, the class was heavily directed. Three different instructors taught 3 different sections. Two instructors (A and B) used nearly identical notes, while a third instructor (C) used a different set of notes. However, all three Spring 2022 instructors gave the same homework and exams, allowing for slight variation of exam problems between time slots. Two sections (A and C instructors) were taught at 8am and gave the same exam, while the other section (B) was taught at noon and had a slightly varied exam but consistent with the 8am version. Each instructor contributed to each exam and to homework assignments throughout the semester. However, the grader between the three sections was not consistent. Several undergraduate graders graded homework throughout the semester, and each instructor graded their own exams, allowing for some variation in consistency of partial credit. This arrangement, however, did ensure that students were exposed to the same topics, same problem types, and same level of difficulty in exams. Instructor A was most senior and has extensive experience in teaching across all levels of the curriculum, especially in Thermodynamics I, though it had been several years since Instructor A last taught that course. Instructor A has also frequently taught courses later in the thermal-fluid sequence, and was the primary designer of homework and exams for Spring 2022 semester Thermo I. Instructor B also has extensive teaching experience, including in Thermodynamics II, but was teaching Thermo I for the first time. Instructor C has the least experience and is fairly new to teaching, though this instructor had recently taught Thermo I in previous semesters without sufficient mentorship/supervision. While the consistency of the Spring 2022 semester was voluntary among Instructors A, B, and C, the department is seeking to implement a more formalized approach to course consistency requirements. Future work toward consistency in this course may yield standardized exams, required assignments/project, competency quizzes, or similar measures after reviewing the full results of this pilot study, as well as after allowing time for identifying pandemic issues versus instructional issues. This paper is only reviewing a preliminary analysis of the pilot consistency semester, Spring 2022, which employed consistent homework assignments and exams, with all faculty contributing at least one problem per exam. While faculty autonomy is important in instructional flexibility of material, faculty (or GTA) egos can also be a hinderance to education if students are given inconsistent instruction and rigor, especially within the same course. Beyond faculty autonomy, other obstacles to developing course and section consistency include course pacing, which can be affected by personal situations of instructor along with student needs, faculty time limitations, and student collaboration/cheating across sections. For the Thermodynamics I course, instructor autonomy has presented the primary obstacles. Here, the authors seek to find the appropriate balance between instructor autonomy and structure in this important pre-requisite course.

It is important to note that consistency of grades does not necessarily translate to consistency of learning outcomes, and this can be seen with the average grade distributions over a period of years in Thermo I, as shown in Figure 1. Even though grade distribution remained consistent during Pandemic semesters, it is clear from subsequent performance that student comprehension pre- and post- pandemic was not consistent. Figure 1 shows that Pandemic grades were not necessarily inflated beyond typical grading in Thermo I course over previous years, with B, D, and F grade percentages being nearly the same, and with the percentage of A grades during pandemic slightly lower and percentage of C grades during pandemic slightly higher. All grades are well-within expected error distributions, however.

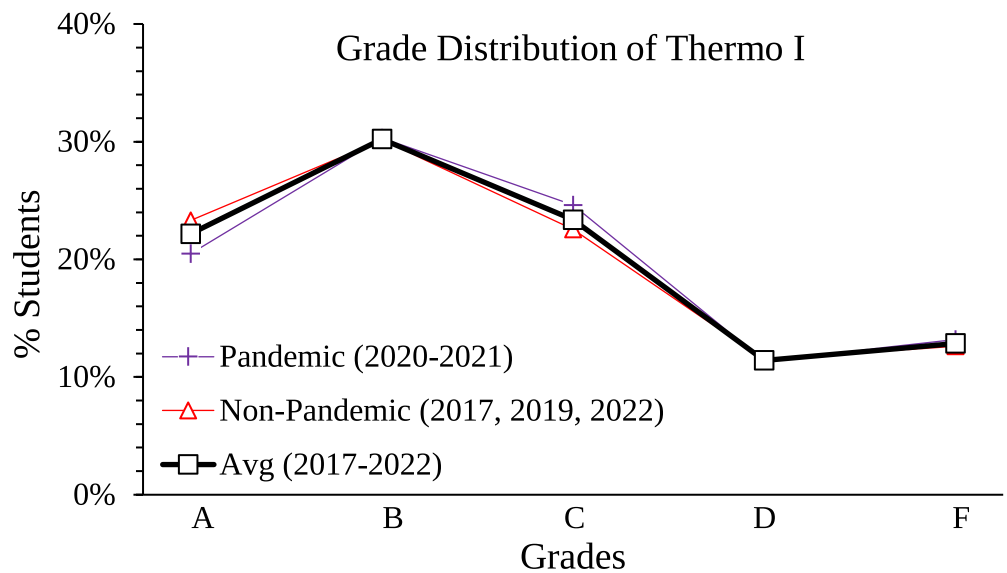

Figure 1. Grade Distribution of Thermo I Sections, Pandemic Years vs Non-Pandemic Years. Averages were performed over 8 sections during Pandemic and 12 sections during Non-Pandemic period. The 20 sections considered herein were taught by over 12+ instructors.

Results and Discussion

Thermo II Comparison

In Thermo II, the distribution of students included 76 total students, 51 who took Thermo I in the Spring 2022 semester, and 25 who took Thermo I in other semesters. Figures 2 and 3 show performance data in terms of overall student GPA and grades on Exams 1 and 2 in the Fall 2022 Thermo II course, respective to the semester students took Thermo I (Figure 2) and their Thermo I final letter grade (Figure 3).

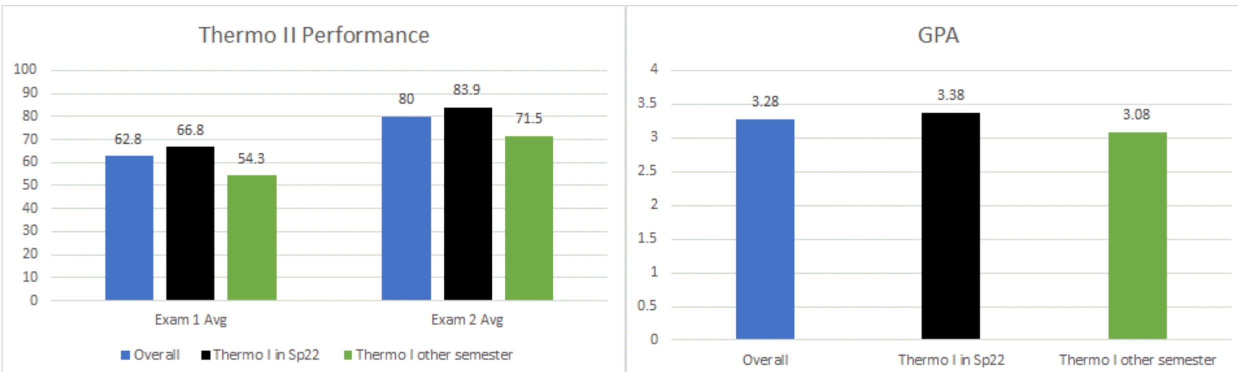

Figure 2. Thermo II performance on Exam 1, Exam 2 and Student GPA relative to semester that Thermo I was taken.

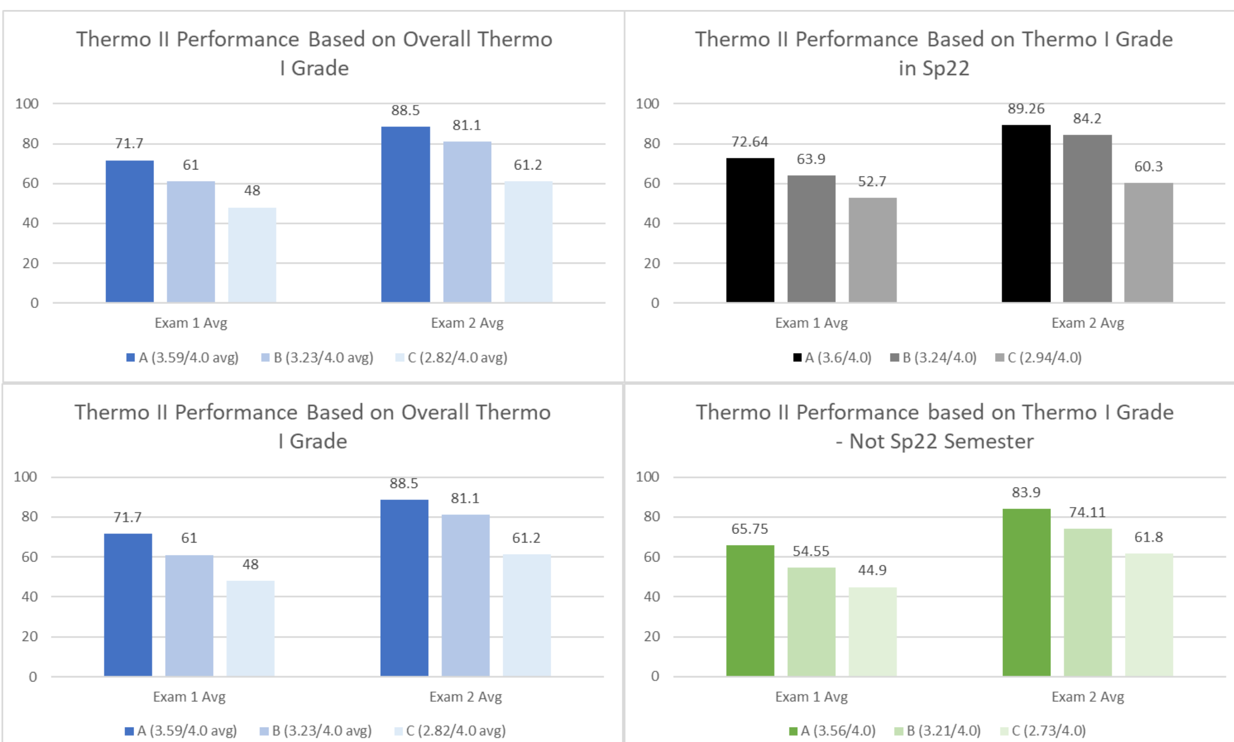

Figure 3. Thermo II Performance Based on Final Grade in Thermo I, semester comparison.

In Figure 2, it can be seen that the students who had a consistent Thermo I experience in the Spring 2022 semester performed better, overall, on the testing metrics in place in the Fall 2022 semester. GPA averages are relatively consistent, though students from Spring 2022 semester do have a higher cumulative GPA. It should also be noted that the Spring 2022 semester students also took Thermo I more recently than most of the "other" semester students. However, this advantage should be relatively negligible by the point in the semester in which exam 2 is reached, and exam 2 still shows a significant advantage to Spring 2022 semester students. Figure 3, however, shows the breakdown of exam 1 and exam 2 performance based on final grade earned in Thermo I, for the overall class and for students who took Thermo I in Spring 2022 versus other semesters. Average GPAs for the students in each category are also shown, with A and B student GPAs being very comparable and more variation seen in C student GPA. When normalized based on Thermo I final grade, it can be seen that the Spring 2022 student performance is higher in all categories except C student exam 2 performance. While not definitive, this indicates that a controlled, consistent experience in Thermo I is likely beneficial to students in subsequent course performance and in accurate grade feedback. For more data, the Fall 2022 Heat Transfer course is also examined.

It should also be noted that in Spring 2022 semester, instructors were encouraged to talk with their students about developing an engineering mindset and systematic approaches to problem-solving, as well as to address general study skills with their class. Since Instructors A and B have more experience in this area, it is expected that they may be more effective at assisting students in developing these study habits. Figure 4 shows a GPA breakdown of students in Thermo II vs their test average in Thermo II (Test 1, Tests 1-2, Tests 1-3).

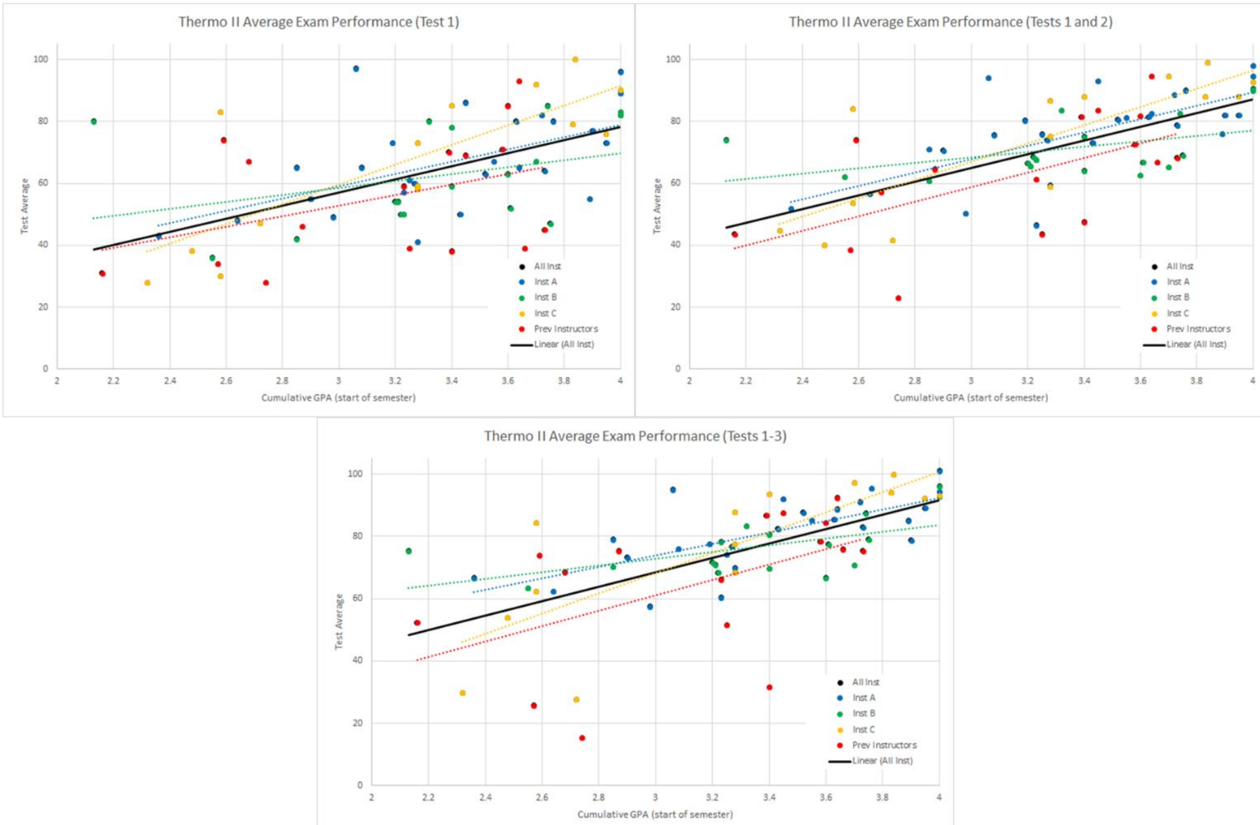

Figure 4. Thermo II Student Exam Performance based on Student GPA, Thermo I instructor.

From Figure 4, it can be seen that Instructors A, B, and C all had student performance on Thermo II exams at levels above the instructors prior to that semester, based on student GPA. It is expected that high performing students (high GPA students) typically achieve well regardless of instruction, and the above analysis represents a proposed metric for evaluating instructor performance beyond SETs. Examining just test 1 performance, that most heavily influenced by a Thermo I experience, it is seen that high GPA students performed better on Exam 1 under all Spring 2022 instructors, with mid-and lower GPA students also outperforming comparable GPA students for Spring 2022 Instructors A and B. However, it should be noted that Instructor C taught across Spring 2022 and previous semesters, while all Instructor A and B students were taught in Spring 2022. Therefore, further examination of instructor C is pursued in Figure 5. It is seen that Spring 2022 Instructor C students, especially at lower GPAs, had significantly better performance on Exam 1 than those who had Instructor C in previous semesters. Therefore, it is highly likely that the change in mentorship and course standardization significantly assisted subsequent student performance, especially those at the lower-end of GPA. Figure 5 also shows GPA vs Exam 1 performance of all Spring 2022 instruction vs. previous semester instruction.

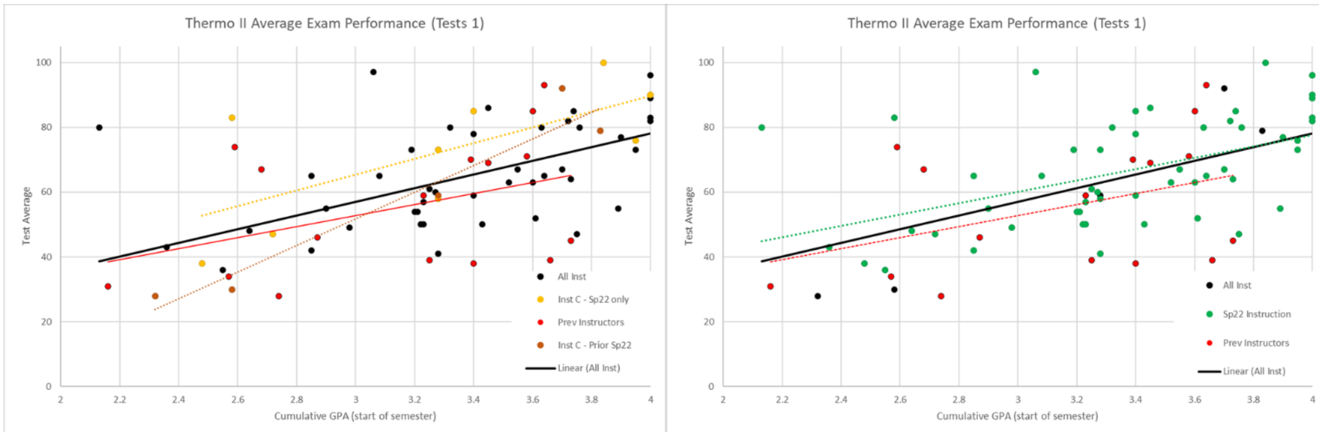

Figure 5. Thermo II Exam 1 Performance vs GPA, Sp22 semesters vs. other semesters.

Heat Transfer Comparison

In Heat Transfer, the distribution of students included 60 total students, 9 who took Thermo I in the Spring 2022 semester, and 51 who took Thermo I in other semesters, which is in stark contrast to the Thermo II distribution which was weighted heavily toward students who had taken Thermo I in Spring 2022. Additionally, in this course, the time span between the courses should present less of an advantage/disadvantage for all performance metrics. Figures 6 and 7 show performance data for Heat Transfer in terms of overall student GPA and Thermo I data, similar to Fig. 2 and 3.

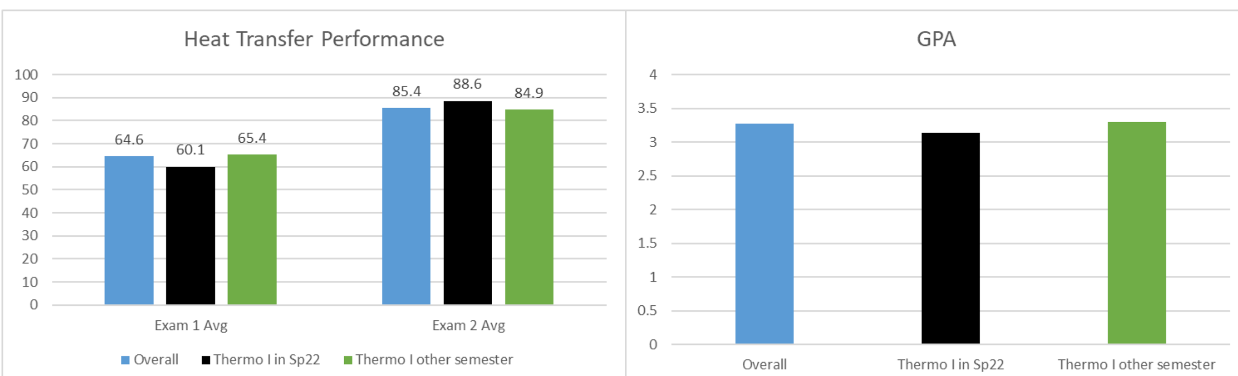

Figure 6. Heat Transfer performance on Exam 1, Exam 2 and Student GPA relative to semester that Thermo I was taken.

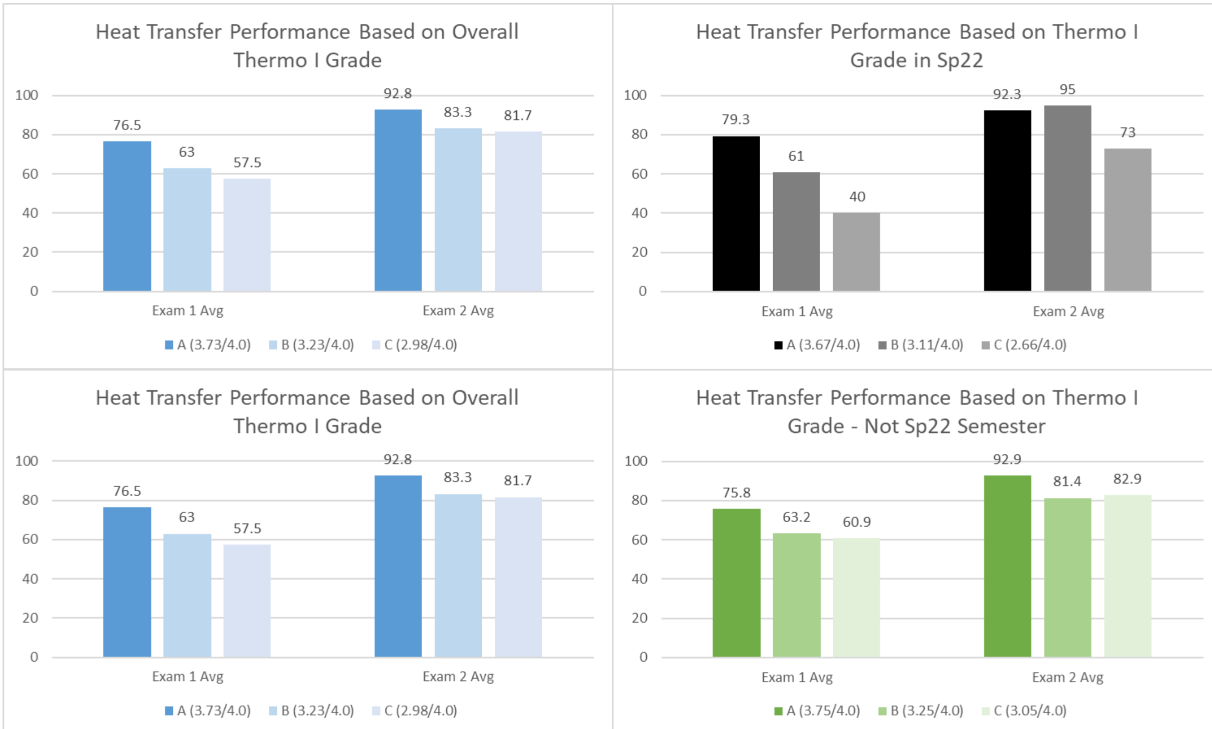

Figure 7. Heat Transfer Performance Based on Final Grade in Thermo I, semester comparison.

In Heat Transfer, the performance of Spring 2022 Thermo I students relative to their peers is not as strong as that seen in Thermo II, however, there are a couple key points to recognize in this comparison. First, the sample size of students from Spring 2022 Thermo I in Heat Transfer is much smaller. Also, the cumulative GPA of these Spring 2022 students is lower relative to the overall class. With that in mind, the data is telling. On the whole, Spring 2022 thermo students performed worse than the overall class on exam 1, but slightly better on exam 2, showing this cohort was able to make the greatest adjustment between exam 1 and 2. The results are more interesting when breaking it down according to final grade earned in Thermo I, however. Of the 9 Spring 2022 Thermo I students in this heat transfer class, the A/B/C final Thermo I grade breakdown is evenly split, with 3 students in each category. For Exam 1 in Heat Transfer, the Spring 2022 A students did better than overall, the B students did slightly worse than their other semester B counterparts, but the Spring 2022 C students did significantly worse. On Exam 2, the Spring 2022 A students did very comparably to the overall class, the Spring 2022 B students did significantly better than the overall class, and, while the Spring 2022 C students still performed below average, they had the highest percent improvement between exam 1 and exam 2. The Spring 2022 B students had the next highest percent improvement. The percent improvement results are shown in Fig. 8.

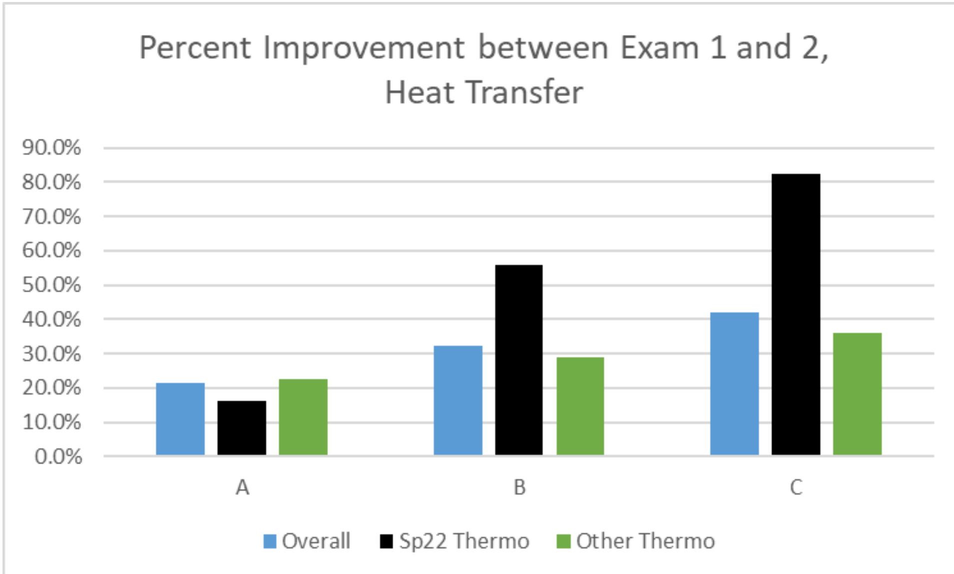

Figure 8. Percent Improvement for Heat Transfer Students, based on Thermo I grade.

Figure 8 indicates that while some of the Spring 2022 Thermo I students may have gotten off to a rocky start in heat transfer, they were adequately prepared and quite capable of improvement. Again, the smaller sample size relative to the rest of the class is significant for all the data acquired in Heat Transfer, but these results at least support an adequate to strong preparation of students in the more structured Spring 2022 Thermo I course. This is further supported by the GPA data versus Exam 1 grade for heat transfer, shown in Figure 9. Since the sample size of Spring 22 Thermo I students in Fall 22 Heat transfer is smaller, there are no Spring 22 students with GPA less than 2.5, therefore, the GPA data truncated at 2.5 is more representative. In that performance metric, it is seen that there is a slightly increased overall Exam 1 performance among the Spring 22 Thermo students.

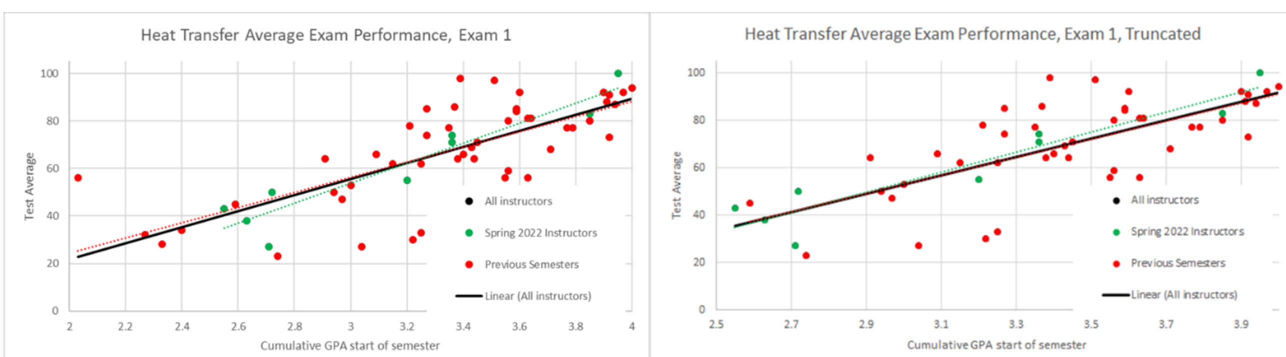

Figure 9. Heat Transfer Exam 1 Performance based on Student GPA

Conclusion and Future Work

The Spring 2022 Thermo I students all got a consistent exposure to concepts and problem-solving in their Thermo I course. Perhaps more importantly, however, they were all held to the same standards in terms of rigor, deadlines, and expectations. In the authors' opinion, this consistency of rigor and expectations is equally important to the students success in subsequent courses. This consistency allowed students not only to do well but to also have the tools to adjust their habits and improve throughout the semester. While with such small samples, definitive conclusions from the data cannot be adequately drawn, the groundwork has been laid for further study to follow these students in subsequent classes. None of these students have entered the ESD course yet, which one author is planning to teach in Spring 2023, when the first small, sample set of Spring 22 Thermo I students should arrive in that course. The Spring 2023 semester will also yield more of these Spring 22 Thermo I students in Heat Transfer and Thermo II. In the Fall 2023 semester, significantly more of this Thermo I cohort should be present in ESD. The instructor for this ESD has thus far reported that Fall 2022 was the worst semester he has seen in terms of student preparation and performance, and he should be interacting with students who took Thermo I in late 2020 through 2021, during which time the least consistent instruction in Thermo I was applied. Ideally, more consistent semesters of instruction in Thermo I, similar to the Spring 22 semester, should be implemented within the department, as well. In reviewing this data, the authors plan to continue analyzing performance based off of Thermo I consistency of instruction and to determine if stricter guidelines or assignment requirements should be put in place for every instructor of that course to best foster student success later in the curriculum.

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Alta Knizley

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Morgan Green

Morgan Green is an Instructor in the Mechanical Engineering Department at Mississippi State University. She is currently pursuing a PhD in Engineering Education, where her research is focused on the development and assessment of professional skills in engineering students. Other areas of interest and research are engineering education outreach and the application of hands-on learning in engineering students. She is the founder and Director of Project ENspire, an engineering outreach event for 4th-6th grade girls now in its eighth year.

Shanti Bhushan

Shanti Bhushan is an Associate Professor of Mechanical Engineering at Mississippi State University. His teaching intertest are in the area of Thermo-Fluid dynamics. He teaches undergraduate lever courses in Thermodynamics and undergraduate and graduate level courses in Fluid mechanics. His primary research is in the area of high fidelity CFD with emphasis in turbulent flow modeling and simulation. He has developed and validated novel turbulence/transition models to enhance robustness of CFD, and applied CFD for the prediction of complex fluid flow phenomena in aerodynamics, hydrodynamics, numerical weather prediction, bio-fluids and nuclear engineering applications. He is a proponent of involving undergraduate students in research, and over the years he has supported 7 undergraduate students, out of which 4 of them opted for Graduate school. He is an active member of ASME and Mississippi Academy of Science.