USING PROACTIVE JUST-IN-TIME INSTRUCTION TO IMPROVE STUDENT PERFORMANCE IN AN INVERTED CLASSROOM

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INTRODUCTION

There have been significant efforts to use the inverted or flipped classroom approach in a variety of courses at both the high school and college levels for some time. Several excellent reviews of the literature have appeared in print recently.[1-5] The basic concept of the inverted classroom is that lecture material and course content are provided outside of class time by recorded lectures or other mostly online delivery methods. The time in the classroom (either physically or virtually) with the instructor is spent doing mostly non-lecture, active learning activities such as working on projects or homework/problem sets often in teams, engaging in discussions, taking assessments, and more. Active learning in itself has been shown to improve student comprehension, satisfaction, problem solving skills, and confidence in engineering and other courses.[6,7] The addition of the inverted classroom has improved student performance, material retention, and the ability to apply the material to problems.[8]

The COVID-19 pandemic has sped up the adoption of the inverted classroom due to the need for online education as physical classrooms were shuttered, social distancing in physical spaces implemented, and quarantining or isolation of students and/or faculty occurred at various and often unpredictable times. These "forced" inverted classrooms, when planned and executed well, showed improved student learning measured by assessments, decreased errors or failure rates of students, and often improved student satisfaction.[9-11] The devil is in the details, as simply placing video lectures online and expecting students to watch them, internalize the material, and learn the concepts have been shown to not be extremely effective at the undergraduate level [8] but may have a better chance at success with students who are highly motived to learn or those at the graduate level. Students must be held accountable (have an immediate assessment/quiz or promptly need the material in an in-class activity that is graded) for the materials that they are required to view outside of class to facilitate their study and use by students.[8, 12-14]

This current study builds on the work of Lo and Hew.[15] They analyzed 29 published inverted classroom studies and concluded that there were three main reasons for student improvement in inverted classrooms: pre-class learning, pre-class and in-class connection, and in-class learning. They use the term "connection" to mean bringing the outside material into the classroom, thereby reinforcing the material. The author of the current study had previously used and studied the inverted classroom in a chemical engineering thermodynamics course [8] and focused on the pre-class learning of the students and the pre-class and in-class connection. This class was the second thermodynamics course required of chemical engineering majors focusing on energy changes of mixtures, phase equilibria, and reaction equilibria of multicomponent multiphase systems. Pre-class learning was facilitated by using the optimal video length of lectures and daily quizzing on the material. Videos longer

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than 15 minutes were found to be less effective.[8] In-class connection (connecting outside lecture material to in-class activities) was enhanced by the instructor having homework problems done during class time directly related to the previous online lectures. The instructor used the majority of the class time to answer student-initiated questions from student groups working on problems during class, which also helped to bring the previous online lecture material into the classroom. Building on the previous work, this work focused on improving the inverted classroom technique by changing how the in-class learning was accomplished by providing proactive just-in-time instruction to individual groups while they were working on their in-class assignments.

There are two common just-in-time techniques used in instruction. Just-in-time teaching occurs when students complete some activities outside the classroom that are reviewed by the instructor before the next class period. During the class period, the instructor provides instruction on gaps of knowledge, errors, misconceptions, or other shortcomings discovered in the students' work.[16] Just-in-time learning is a process whereby instruction materials (typically online) are available to the student, but do not have a set schedule for completion. Instead, when the need arises, a student will access materials to learn what they need in the moment to solve a problem, answer a question, or describe a situation. Just-in-time learning is very common in the professional training environment.[17] The technique implemented in this study is a bit different than the common just-in-time techniques and is referred to as proactive just-in-time instruction. In this method, the instructor observes students doing work. When a mistake, lack of understanding, confusion, or error in approach is observed, immediate personalized instruction is provided. The previous study [8] allowed students to make mistakes and feedback was provided later, when their assignments were graded, as opposed to catching the error in the moment.

RESEARCH DESIGN

Previously [8] an inverted classroom was studied in a junior level chemical engineering thermodynamics course at Villanova University in the fall of 2013 and 2014 (108 students) and compared to the previous four course offerings that were taught in a traditional lecture style with 188 students in the previous three years. The average class section size was 27 students. The class met three times a week for 50 minutes for a total of 42 class meetings followed by a final exam. The inverted course detailed in Weinstein [8] discusses how video length influenced comprehension and student performance on quizzing, how required graded quizzes affected students completing their required pre-class work, and how the inverted style improved student exam performance, especially for the lower third of the class. The skill level of the students was believed to be equal across all years based upon their incoming standardized test scores being equivalent. This inverted course also used some just-in-time teaching where quizzes were used, and questions that students struggled on were covered in a short review in the beginning of the class. Just-in-time learning was also used by the students, as all course content was available throughout the course and students could access it when needed if they ran into a gap in their knowledge or understanding, although due dates were established for specific content. These just-in-time techniques were continued in this current study along with the addition of proactive just-in-time instruction.

The author took a break from teaching this course due to administrative responsibilities but returned to teaching it in the fall of 2020; hence the gap in data. The curriculum in the major had since been adjusted, and the course was then moved from the fall of junior year to the spring of sophomore year for the spring of 2021 and 2022. The three most recent offerings had 168 students, with an average class section size of 28. Since the university went test optional for some of these most recent students, standardized test scores would not be a reliable source of data to show the equivalent skills of the different years as had been done in the previous study.[8] Instead, the previous course grade (for the first chemical engineering thermodynamics course required as a prerequisite for this current course) was used to judge the skill set of the students. The previous course has been taught by the same instructor in a traditional lecture style with active learning modules spread throughout the class period and did not use the inverted classroom. The skills used in the current thermodynamics course build heavily on the concepts, mathematics, and theories learned in the first thermodynamics course. In particular, temperature-pressure-volume effects on systems, single variable and partial derivatives, definite integration, energy balances (with heat and work interactions), the first and second law of thermodynamics, and equations of state were built upon. Students self-reported their previous course grade in the CATME team maker software,[18] which was used to generate homework teams. This software was used for all three types of courses: traditional lecture, inverted classroom, and inverted classroom with proactive just-in-time instruction. On a traditional 4.0 GPA scale (A = 4.0, A- = 3.67, B+ = 3.33, etc.), the previous thermodynamics course had final averages with 95% confidence intervals of 2.9 ± 0.2 for the traditional lecture, 3.1 ± 0.3 for the inverted classroom, and 3.1 ± 0.2 for the inverted classroom with just-in-time learning and hence were believed to each have students of basically equal skill sets (using a t-test showing no statistical difference in the averages) of important thermodynamic knowledge entering the class. It would also be expected, if the current students were better prepared, that their quiz scores (before new techniques in this study were implemented) would be higher, which was not the case.

The course material delivery for these three most recent offerings was the same as previous,[8] using the inverted classroom technique with identical videos and quizzes. Quizzes were done in the learning management system, and students did not have access to them afterward to share with other classes so the identical quizzes could be repeated. Homework sets (11 total) and exams (3 and a final exam) were changed but were created targeting identical difficulty level using previous offerings as explained in detail in Weinstein [8] to ensure comparisons could be made from year to year in student performance. Exams were mostly calculations requiring a numerical solution, with roughly 20% of the points associated with answers requiring interpretation of equations, trends, graphs, data, etc. In the fall of 2020 and spring of 2021, the class was offered in person in a social distanced mode with students wearing face coverings in the class and sitting six feet apart. The social distance policy allowed for a maximum of 15 minutes of close proximity to others during a class period. Students were able to observe other students work and would often pass papers or get close for short periods of time. Some students would participate in the class online via Zoom® due to isolating or quarantining requirements, and they would be placed into breakout rooms with their group when required. Students typically shared work between in person and online students via text messaging photos or pdfs in attachments in email for Microsoft Excel® files or Mathcad® files. In the spring of 2022, face coverings were worn for about half the course, there was no social distancing, and again some students would be online at various points of the course due to isolating or quarantining requirements.

Besides the restrictions due to the pandemic, the only change made in the three most recent iterations of the course compared to the previous inverted classroom offerings was how the in-class learning was done. Previously, after receiving a short review if needed (just-in-time teaching), students would break into their teams of three and work on their roughly weekly homework that had a problem or two that focused on the video lecture material that was due for that day. The instructor would be summoned to groups to answer questions and provide clarifications when requested. Students could access materials online and use just-in-time learning if needed. In the recent offerings the interaction of the faculty was changed to provide proactive just-in-time instruction. Instead of just waiting to be called to a group to answer questions, the faculty member would proactively roam the room and observe what groups were working on and would quickly identify mistakes or bad approaches that were occurring. He would ask the students questions, point them to pages in the class notes, provide some quick instruction, or ask them to rewatch a portion of the lecture video to assist them. He would also go to a group when requested to answer questions. Interaction time with the students was measured using the stopwatch app on a smart phone. Running time was recorded as either answering student-initiated questions or proactive just-in-time instruction. The remaining class time (not including the quiz or any summary given) was deemed to be faculty idle time. Faculty time of answering questions or being idle was not measured in the previous inverted classroom without proactive just-in-time instruction where the faculty would only interact with a student group if summoned by the group.

Student performance on the frequent quizzing (before proactive just-in-time instruction occurred) was compared to traditional inverted classroom offering. It is expected that the quiz scores should not change due to the proactive just-in-time instruction presented after the quiz was taken. The performance on the homework assignments, which would be expected to have higher scores due to faculty intervention to prevent errors, was also compared to previous offerings. The true test as to the effectiveness of the proactive just-in-time instruction would be how the students performed on their exams. It was hoped that the new approach would improve the student learning and their performance on exams.

Averages on quizzes, exams, and homework assignments are reported at 95% confidence limits. The Mann-Whitney non-parametric test [19] was used to show if there was a significant difference between the average scores from the inverted classes when compared to the inverted classes with proactive just-in-time instruction for quizzes, exams, and homework averages. As was done previously, all averages presented used the t-test for equal means.[8]

RESULTS AND DISCUSSION

Quizzes had no partial credit, consisted of five questions, and were automatically graded by the learning management system. The inverted classroom quiz averages were compared to the those with proactive just-in-time instruction added (2020-2022), and results for the class averages as well as those for the top, middle and bottom third (based upon their total exam averages) of the class are presented in Table 1. As expected, there was no significant difference in the quiz averages (with the addition of proactive just-in-time

TABLE 1
Daily quiz averages (95% confidence interval) for inverted classes compared to identical quizzes given to inverted classes with proactive just-in-time instruction.

	Inverted Class	Inverted Class with Proactive Just-in-Time Instruction
Overall	82 ± 1.6	83 ± 1.5
Top 1/3	92 ± 1.3	93 ± 1.2
Middle 1/3	85 ± 1.8	84 ± 1.7
Bottom 1/3	70 ± 3.9	73 ± 3.7

instruction) as that instruction was provided on the material after the quizzes were taken by students.

It was expected that homework grades would rise with proactive just-in-time instruction provided when students were working on homework assignments during class time. Eleven homework sets were given each year with 3-5 problems per set. Homework was done in teams of 3 students with the occasional team of 2 or 4 students. One solution was submitted per team. Teams were formed using the CATME software [18,20] with the built-in recommended questions and weighting factors used. Homework received partial credit and was out of 30 points with a 1-point trivia bonus question on thermodynamics, making the maximum score on homework of 103.3%.

Faculty time was measured in the classes with proactive just-in-time instruction and is reported in Table 2 as a percentage of total class time. The previous inverted class did not measure time the faculty spent answering student-initiated questions or being idle. However, the author was able to access 21 previous recordings of these classes (all that were available) and estimates that roughly 70% of the time was spent answering questions with 30% of the time being idle. The students tended to struggle more without the proactive just-in-time instruction and initiated more questions. The proactive just-in-time instruction appears to increase student-faculty interaction (reduced faculty idle time), which in itself can improve student learning.

During the initial stage of the course, there was significant proactive intervention as the students were building up their thermodynamic-related math skills and covering many topics and concepts that would come back and be used in the course later (such as partial derivatives, residual properties, energy calculations, and more). As the course progressed, the instructor spent less time correcting errors and more time answering student-initiated questions. Some down time was also recorded where roaming around the room did not require any intervention. Near the end of the course, more questions were occurring, and less proactive just-in-time instruction was required as students had more thermodynamics knowledge and problem-solving skills and therefore were able to handle more roadblocks on their own over time. Interestingly there was no statistical difference in the homework grades as the course progressed (early homework versus homework later in the course). As expected, the homework grades for the course with proactive just-in-time instruction (95 ± 5%) were statistically higher than those in the course where proactive just-in-time instruction was not provided during the homework and only student-initiated questions were answered (85 ± 4%).

Others have found that just-in-time instruction and instantaneous feedback on homework with instruction provided around mistakes have shown to improve exam scores.[21-23] Often the feedback is provided via an automated grading system. In this study feedback and proactive just-in-time instruction were provided by the instructor while students were working on homework. Additionally, graded homework provided feedback to the students at a later date.

Previously, the author showed that the inverted class approach improved student performance on exams and had the biggest impact on the lower third of the class.[8] The lower third had their exam averages improve by almost 7 points (on a 100 point scale) while the top third only saw a slight improvement of 2 points due to the use of the inverted class.

It is important to note that the method for creating exams of equal difficulty was consistent over time and is described in the previous work.[8] By using previous years of exams as guides for degrees of difficulty of questions and a standard grading system (points for specific parts of a problem), the author was able to achieve the same level of difficulty and uniform grading for the traditional class, the inverted class, and the inverted class with just-in-time learning. To verify the grading was consistent and did not contain bias, the author regraded the final exam from the spring 2022 class (7 months after the initial grading) and the fall 2012 class (10 years after the initial grading). The regrading produced the same exam average (± 1%), with 86% of the 2012 exams and 84% of the 2022 exams receiving the exact same score. Figure 1 shows the degree to which adding proactive just-in-time instruction improved exam performance with the inverted class. Table 3 shows the compression between the top, middle, and bottom third (based on exam averages) class performance on exams for each of the three types of classes.

Proactive just-in-time instruction enhanced the overall class exam average by 4 points. While the inverted classroom had a larger effect on the lower performers in the class, the addition of just-in-time learning provided a roughly equal boost to exam scores for all levels of students in the class, with the top third gaining 3 points, the middle third gaining 5 points, and the bottom third gaining 4 points.

TABLE 2
Percentage of faculty time (95% confidence interval) with students working on homework throughout the inverted course with just-in-time learning.

	Answering Question (% of time)	Proactive Intervention Providing Just-in-Time Learning (% of time)	Idle (% of time)
Classes 2-12	20 ± 4	75 ± 8	5 ± 2
Classes 14-21	28 ± 5	61 ± 6	11 ± 3
Classes 23-31	25 ± 6	62 ± 9	13 ± 5
Classes 33-42	34 ± 4	47 ± 5	19 ± 5

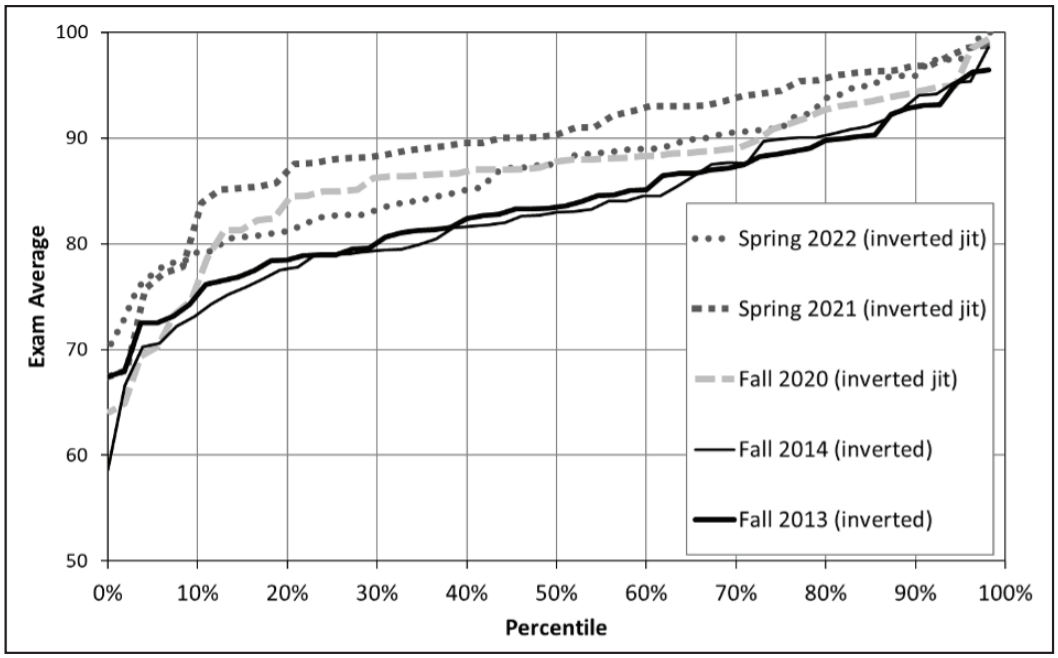

Figure 1. *Average exam scores from the inverted classes (2013-2014) and the inverted classes with proactive just-in-time instruction (jit) (2020-2022) based upon class rank percentile.*

TABLE 3
Average exam scores (95% confidence interval) for all three types of classes. Class was partitioned based upon average exam score.

	2009-2012 (Traditional)	2013-2014 (Inverted)	2020-2022 (Inverted jit)
Overall	79.8 ± 1.4	83.2 ± 1.3	87.6 ± 1.1
Top 1/3	89.2 ± 0.7	91.1 ± 1.0	94.5 ± 0.7
Middle 1/3	81.4 ± 0.6	83.3 ± 0.6	88.2 ± 0.3
Bottom 1/3	68.6 ± 1.6	75.3 ± 1.5	79.4 ± 1.5

DIVERSITY, EQUITY, AND INCLUSION

Finally the author verified that students of color and females (all through voluntary self-identification in the CATME team maker software [18]) did not perform statistically different than the class as a whole on quizzes, homework, or exams. The default settings on the CATME team maker software did not ask for sexual orientation and hence that was not explored, but may be considered for a future study. No students chose other/prefer not to answer in the gender question. Since the number of Hispanic, Black and other ethnicities was relatively small, they could not statistically be used as individual groups to compare to the whole class average. Hence, those three ethnicity choices were considered students of color as one group of students to make comparison. The inverted classroom with proactive just-in-time instruction appears to be equally beneficial across gender and students of color.

CONCLUDING REMARKS

The addition of proactive just-in-time instruction to the inverted class, with the instructor actively intervening while student teams are working on homework problems during class time, was shown to improve performance on exams by 4 points across all levels of students when compared to students in an inverted class where the instructor would only answer questions initiated by students while they were working on homework. Both the inverted class and the inverted class with proactive just-in-time instruction had higher exam performance than a traditional lecture course. The inverted class alone had previously been shown to more significantly improve the lower third performing student by an average of 7 points and the entire class an average of 3 points higher while compared to a traditional lecture class. With the addition of proactive just-in-time instruction, the lower third performed an average of 11 points better while

the entire class had an average of 8 points higher when compared to a traditional lecture class. By using proactive just-in-time instruction during homework completion during an inverted class, student performance in the course can be greatly enhanced, improving exam averages by a full letter grade. It is important to note that classroom management was essential, as is with most classrooms, to making this teaching method work. The instructor needed to be sure to not let groups wait too long to get their questions answered. Furthermore, the instructor had to use judgement as to when to jump in and help. Some struggling on solving problems is good, while too much can be discouraging and solidify incorrect knowledge.

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