



Can Students Self-Generate Appropriately Targeted Feedback on Their Own Solutions in a Problem-Solving Context

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Introduction

The present investigation was performed in the context of a required, junior-level chemical engineering course on kinetics and reaction engineering. The learning objectives for the course include student ability to analyze reactor data for the purpose of finding a reaction rate expression, to predict the effect of changes in operating parameters upon the performance of a reactor system and to design a reactor system to meet given performance specifications. Fulfilling each of these learning objectives involves formulation of mathematical models for chemical reactors, solution of the resulting set of model equations and interpretation of the results. The course can be classified as a problem-solving course since that is the primary activity students are engaged in.

In a very common approach to teaching a problem-solving course, the instructor first presents information that students will need when solving a particular type of problem. The instructor then demonstrates to the students how that information is used when solving a particular type of problem. Often this occurs during lectures given by the instructor. Students are then assigned homework problems of that type which they independently solve and submit. The submitted homework is graded and the score is factored into the grade they receive for the course. The graded solutions returned to the students may include written comments, and a correct solution is also made available. Periodically the students take an exam with questions that span the topics and problem types from multiple homework assignments. The exams are graded and returned to the students in a fashion similar to the homework, and the score is factored into the course grade. Often the weighting of the exam scores in the final grade is heavier than that of the homework assignments. At the end of the course a cumulative exam may be given, spanning all topics and problem types considered in the course. For present purposes, the teaching method just described will be referred to as the “traditional-lecture” approach, where “traditional” describes the use of homework and “lecture” denotes the class format.

In this traditional-lecture approach, the homework assignments are intended to serve a dual purpose. First, they provide a means of assessing student attainment of the learning objectives. Additionally, it is expected that solving the homework assignments will help students learn and meet those objectives. If solving homework assignments does help students learn, then it would be expected that students' exams scores would increase as the amount of homework they completed increased. To test this expectation, records for 452 students from 10 offerings of the course being studied were examined. Those 10 offerings were taught using the traditional approach by the same instructor between 1986 and 2005. The class sizes ranged from 28 to 58. Overall course scores and grades sometimes include factors such as participation, attendance, etc. that are not direct measures of how well the students met the learning objectives. For this reason, the combined exams scores, normalized to a 100-point basis, were used here as the measure of student attainment of the learning objectives. The students' exams scores are plotted as a function of the percentage of the homework assignments that the students submitted in Figure 1.

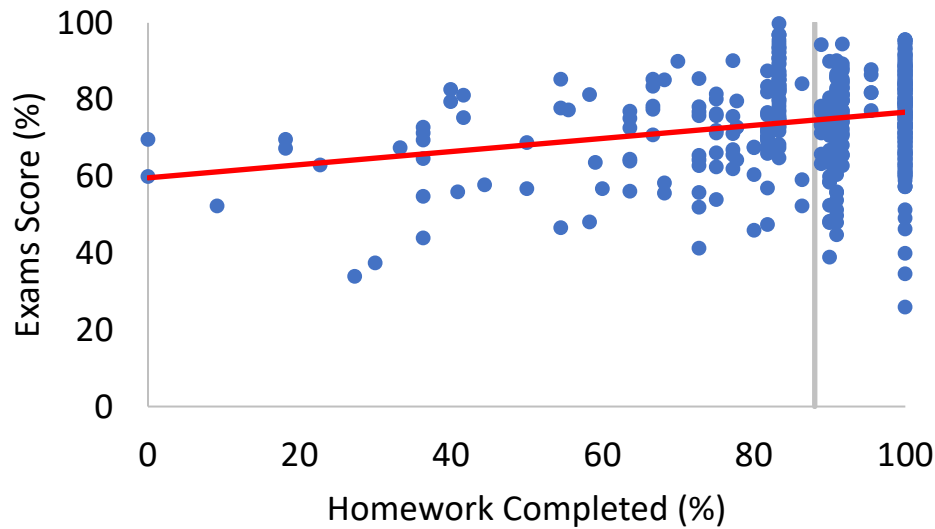


Figure 1. Correlation between the percentage of homework assignments submitted and exams scores in 10 offerings of a problem-solving course taught using the traditional-lecture approach. The gray line is the average percentage of assignments submitted (88%) with the trendline shown in red.

The average percentage of the homework submitted in this data sample was $88.0 \pm 0.8\%$. The slope of the trendline in Figure 1 is 0.17 ± 0.03 . This means that on average, the students who completed all of the assignments earned 17 points more than those who did not complete any assignments. The figure further shows a 70-point range of exams scores (26 to 96) among the students who did *all* of the homework. Indeed, when the exams scores distributions of the students who submitted less than the average amount of homework and those who submitted more than the average were compared, Figure 2, it was found that the distributions were statistically equal (99% confidence level), with means of 73.7 ± 2.8 and 75.2 ± 1.7 , respectively.

The small magnitude of the trendline slope in Figure 1, the wide range of scores for students who completed all the homework and the equivalence of the two distributions in Figure 2 were unexpected. One possible explanation is that many of the students who completed a high percentage of the homework did not make a sincere effort when doing so. That is, since the homework was being graded and counted toward their course grade, perhaps they turned in most of the assignments in the hope of getting some points, even if they hadn't made a good effort to obtain a correct answer. A second possible explanation is that homework is not effective in helping students learn [1-9]. A third possibility is that the manner in which homework is implemented in this traditional-lecture approach does not adequately support student learning.

Two well-established principles of learning [10] are that (1) "goal-directed practice coupled with targeted feedback are critical to learning" and that (2) "to develop mastery, students must acquire component skills, practice integrating them and know when to apply what they have learned." It is argued here that there are two types of targeted feedback on practice that are beneficial during problem solving. The first type of feedback alerts the problem solver when they have made a

mistake. Automated homework systems are increasing in popularity because when using them, the feedback of this kind is immediate, allowing the problem solver to correct the mistake before proceeding with the solution [11-14]. The second type of feedback is metacognitive [15]; it causes the learner to examine their thought processes while they were solving the problem and to identify (and correct) the points when their thought processes were flawed, leading to a mistake.

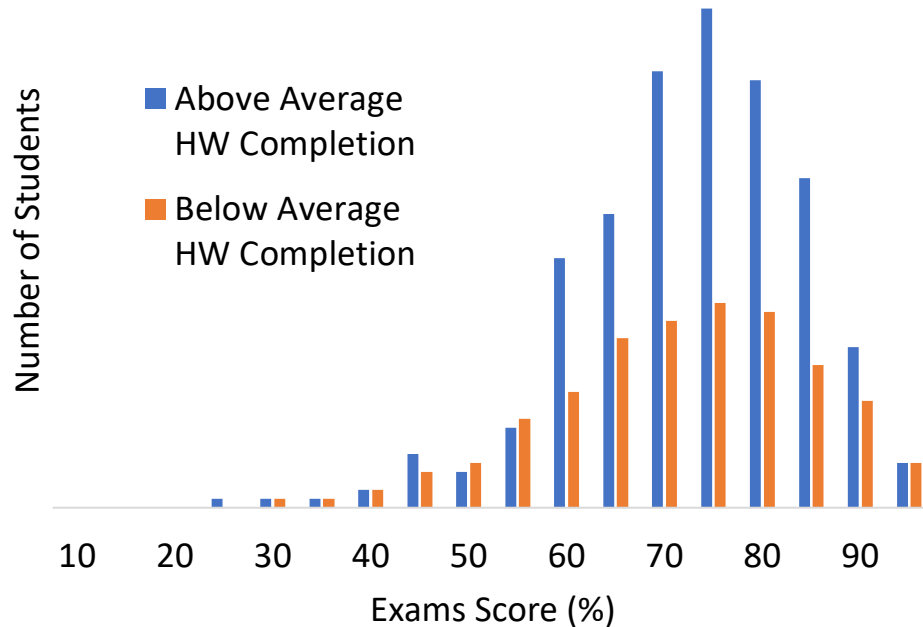


Figure 2. Comparison of the exams scores distribution of students who submitted an above average number of homework assignments to that of students who submitted a below average number of assignments in courses offered using the traditional-lecture approach.

The second learning principle above describes what the learners should be practicing: having acquired the component skills and knowledge they will need, they must practice integrating them in a manner that leads to the solution of a given problem. Clearly the component knowledge must include equations and the assumptions inherent in them, theory and definitions and the component skills must include mathematics, use of computational tools, etc. Here the ability to identify each different type of problems is considered an essential component skill and knowing the general approach that is used to solve each type of problem is considered essential component knowledge.

To illustrate, in the course used for this study, each of the three learning objectives require the problem solver to write mass and energy balances for a reactor, but in one problem type those equations are fit to experimental data, in a second they are solved to obtain an answer directly and in a third, they are solved and revised repeatedly to obtain an answer. Thus, the problem solver needs to know how to differentiate between the different types of problems, and then, having identified the problem type, they need to know the way that the model equations are manipulated when solving that type of problem. In the remainder of this document, “problem-

type identification” should be taken to include the ability to identify a problem’s type and the knowledge of the general process for solving that type of problem.

Research Hypotheses

On that basis, the traditional-lecture approach may not provide students with properly timed opportunities to practice, the teaching and practice it does provide may be missing essential components and the feedback it provides may not be properly timed or targeted [16-28]. The homework in the traditional-lecture approach is used for assessment; there are no opportunities for students to practice and receive feedback on their solution prior to being assessed. A related problem is found in the timing of feedback to the students: it occurs *after* their learning has been assessed. That is, the correct solution to the homework assignment is made available after the assignment has been submitted. If a student makes a mistake on a homework assignment and, through the feedback, learns from that mistake (so that they will not repeat the mistake), that learning is not reflected in the assessment of their learning because the learning took place after the assessment was made. That learning from their mistake can only be demonstrated and assessed if a similar problem is encountered in subsequent homework or on an exam.

A more subtle problem with the feedback received by the students is that it focuses their attention on *what* was wrong in their solution and less (or perhaps not at all) on *why* they made that mistake. The feedback provided (correct solution and perhaps written comments) may lead to some students engaging in metacognitive analysis, but others will stop once they see *what* they got wrong or *where* they made a mistake. Better targeted feedback would cause the students to examine their thinking at the time they made the mistake, identify misconceptions or add missing knowledge, and thereby increase the depth of their understanding and reduce the likelihood of repeating the same mistake. That is, improved feedback would additionally target *why* they made the mistake.

Wrappers are typically writing assignments that ask a student to reflect upon their thinking at the time they performed an assessment task such as an exam. Exam wrappers typically cause students to examine their study habits and approaches, identify aspects that are not proving beneficial and implement different approaches to study [29-33]. Wrappers can be applied to homework [34] and activities other than exams, and they can ask students to reflect upon aspects of their thinking other than the way they studied and prepared. In the present case, a wrapper can ask students to reflect upon the thought processes they used to solve a problem.

Finally, it is worth noting that solving a problem necessitates the use of problem-type identification. In terms of the course used in this study, when given a problem, a student must first determine whether it is a kinetics problem, a reactor modeling problem or a reactor design problem. Then, having done that, they must know the general procedure for solving a problem of that type. Using the language of the second principle of learning presented previously, problem type identification is a necessary component skill that very often is not explicitly taught, irrespective of the teaching approach being used.

In part, this can be attributed to expert blind spot [35]. An expert identifies the type of problem with ease and without conscious thought [36]. Because problem identification occurs so easily

and naturally, the expert may never mention that they first had to identify the problem type nor explain how they made that identification. Instead, the expert immediately starts to implement the general procedure for solving that type of problem. In this way, the procedure is not explicitly mentioned or taught and it is not associated with the type of the problem. Instead it is presented implicitly so that the student is left to (a) generalize the steps in the solution process from watching the expert apply them and then (b) associate those steps with that particular problem type. Some experts describe their thought processes as they solve a problem, e. g. "... I know that next I need to write a mole balance" However, it is rare for the identification of problem type and the associated general process for solution to be *explicitly* taught [35, 37-39].

The effect of failing to explicitly teach problem type identification is exacerbated because the students may never get to practice them prior to taking an exam. In a typical course, a particular type of problem is presented in class. The next homework assignment contains problems of this type. Students don't need to identify the problem type because they know it is the type that was just presented in the previous class and they know they need to use the solution procedure that was used in class. Additionally, if a textbook is being used, all the problems of that type are found in one chapter, so the students know what type of problem it is by the chapter it came from, and not because they are able to identify it. For this reason, a student may never need to identify the type of a problem until they encounter it on an exam where it is mixed with problems of other types. At that point, they may never have practiced identifying problems of that type, and once again, their learning is being assessed on the exam before they have had an opportunity to practice.

The first hypothesis tested in this study is that providing students an opportunity to practice problem solving and receive feedback *prior to assessment* would improve learning as reflected in exams scores. The second hypothesis underlying this study is that explicitly teaching problem-type identification and affording students opportunities to practice it would improve learning. The third hypothesis being tested is that when problem-type identification is explicitly taught, students can self-generate feedback that targets metacognitive analysis of their homework solutions through the use of homework wrappers.

Methods and Results

The same instructor taught the course throughout this entire study. The methodology consisted of changing one or more aspects of the approach used to teach the course and then measuring the percentage of the homework assignments completed and the exams scores of the students taking the course. The resulting data were plotted directly, a trendline was fit to them and the average percentage of homework completed was determined. Then the distributions of exams scores for students who completed more than the average amount of homework and for those who completed less than the average were compared. The results can be summarized in plots of the types shown in Figures 1 and 2.

The intent of the changes in teaching approach was to improve the type and timing of student opportunities to practice problem solving and the targeting and timing of the feedback provided to students, as summarized in Table 1. It should be noted that Table 1 reports the practice and feedback utilized in each teaching approach in this study. For example, Table 1 indicates that

problem-type identification was not implemented in the course offerings that used the traditional-lecture approach in the present study; this does not mean that problem-type identification couldn't be implemented in the traditional-lecture approach.

Table 1. Practice and feedback for each teaching approach as implemented in the present study.

Teaching Approach	Practice		Feedback	
	Type	Timing*	Target	Timing
Traditional-Lecture	No Problem ID	During	Mistake ID	Post
Traditional-Flipped	No Problem ID	Pre/During	Mistake ID	Immediate/Post
Effort-Flipped	No Problem ID	Pre	Mistake ID	Immediate/Pre
Wrapped Effort-Flipped	With Problem ID	Pre	Mistake ID Metacognition	Immediate/Pre Pre

*Relative to Assessment

The first change in the approach used to teach the course was to “flip” the class. Specifically, videos were created to present the information that had been conveyed via lectures. Students were expected to view a set of such videos prior to each class meeting. Typical class meetings began with a brief review of information and techniques from the videos. This was followed by one or two learning activities. The activities were typically performed in small, self-selected groups. The majority of the learning activities entailed solving problems. For each new type of problem, the in-class problem solving was initially scaffolded in a way that emphasized the process for solving that type of problem. Neither problem type identification nor problem solution processes were explicitly taught, however. During these activities, the instructor was circulating through the class, observing and interacting with the students and answering questions. If one particular misconception or question was repeated, the activity would be briefly interrupted and the instructor would discuss the that point before the activity resumed.

The use of homework in this phase of the study was not changed. Each assignment was submitted by the students after which it was graded for correctness and returned to the students along with making the solution available. The teaching approach used during this phase of the study will be referred to as the traditional-flipped teaching approach because homework was implemented in the traditional manner, but content was delivered in a flipped classroom format. In terms of practice and feedback, Table 1, the traditional-flipped approach retains all of the practice and feedback characteristics of the traditional-lecture approach because the homework implementation is the same. However, the in-class problem solving activities add an opportunity to practice and receive feedback before and separate from any assessment. Moreover, the mistake identification feedback during the in-class activities is immediate. Thus, the new characteristic introduced by the traditional-flipped approach is the timing: both practice and feedback occur prior to assessment. (They still occur following assessment, as well.)

During this phase of the project, records for 366 students from 7 offerings of the course between 2006 and 2012 were examined. The class sizes ranged from 31 to 74, and the results are shown in Figures 3 and 4. The slope of the trendline in Figure 3 is 0.287 ± 0.035 , and the average

percentage of homework completed was $88.8 \pm 0.9\%$. The average exams score of students who completed more than the average amount of homework was 77.9 ± 1.7 compared to 68.7 ± 3.2 for those who completed less than the average.

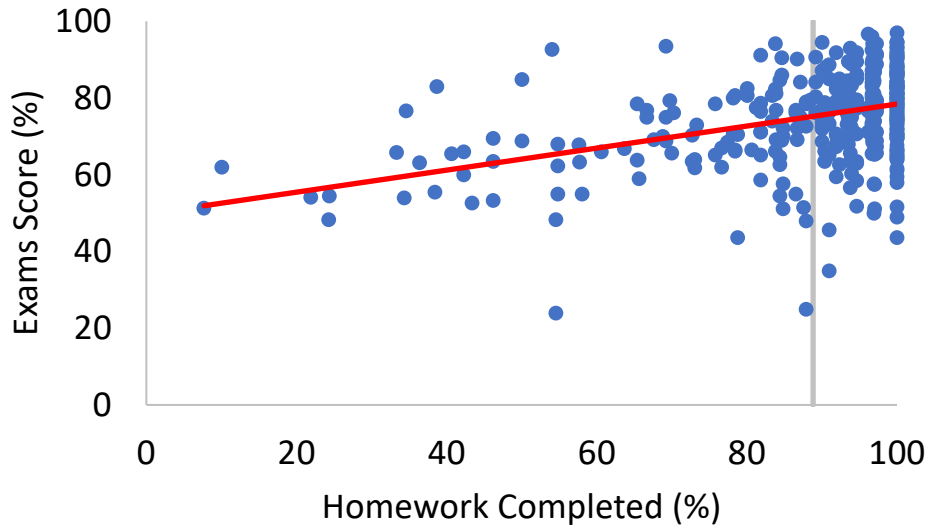


Figure 3. Correlation between the percentage of homework assignments submitted and exams scores in 7 offerings of a problem-solving course taught using the traditional-flipped approach.

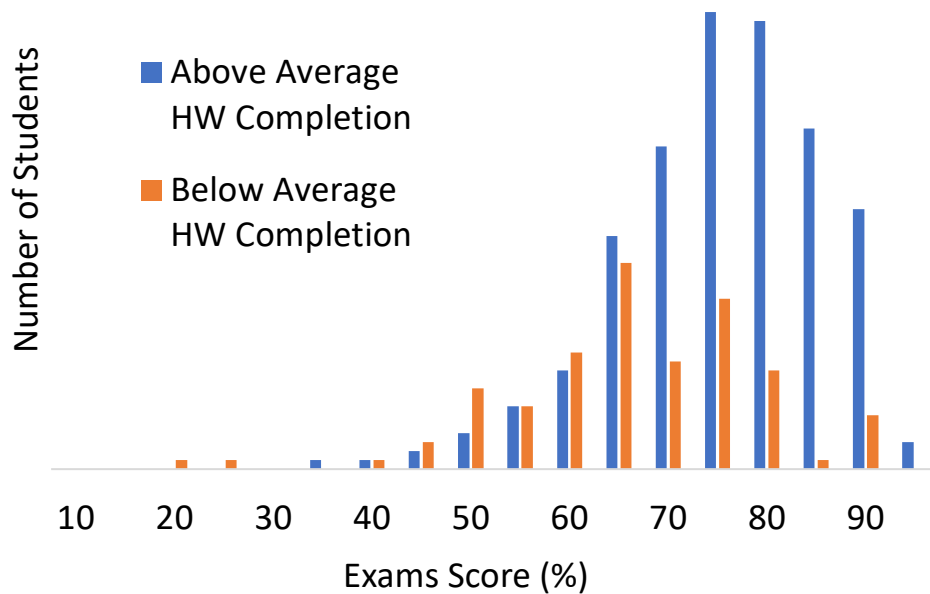


Figure 4. Comparison of the exams scores distribution of students who submitted an above average number of homework assignments to that of students who submitted a below average number of assignments when the course was taught using the traditional flipped approach.

In the second phase of the present study, the flipped classroom teaching method was retained, but the implementation of homework was modified. Most of the homework solutions submitted by the students were graded only on the basis of effort. Each submitted assignment was briefly examined and classified as either (a) showing little or no effort, (b) showing effort toward a solution, but not completing the formulation of a solution, (c) formulating a solution, but not performing the calculations and obtaining an answer or (d) formulating a solution and performing the calculations to obtain an answer. In making this classification, no consideration was made as to whether the formulation was correct or whether the answer obtained was correct. After the assignments were submitted and graded in this way, they were returned to the students and a correct solution was made available. Generally, there were very few comments on the returned solutions due to the cursory nature of the grading in this approach. A much smaller number of homework assignments were graded on the basis of correctness, but these assignments were always preceded by at two or more assignments that involved the same type of problem and that were graded on the basis of effort.

The teaching approach used during this phase of the study will be referred to as the effort-flipped teaching approach. The homework assignments that were graded only on effort represent opportunities for students to practice problem-solving prior to the assessment of their learning. Similarly, the feedback on this homework was delivered to the students prior to assessment (i. e. before the assignments that were graded for correctness). Thus, as indicated in Table 1, the quality and type of practice and feedback are the same as in the traditional-flipped approach. The timing of the practice and feedback is the only difference: it all occurs prior to assessment.

Records for 222 students from 3 effort-flipped offerings of the course in 2013, 2014 and 2016 were examined. The class sizes ranged from 72 to 78, and the results are shown in Figures 5 and 6. The slope of the trendline in Figure 5 is 0.256 ± 0.043 , and the average percentage of homework completed was $86.2 \pm 1.3\%$. The average exams score of students who completed more than the average amount of homework was 74.8 ± 2.6 compared to 65.5 ± 4.1 for those who completed less than the average.

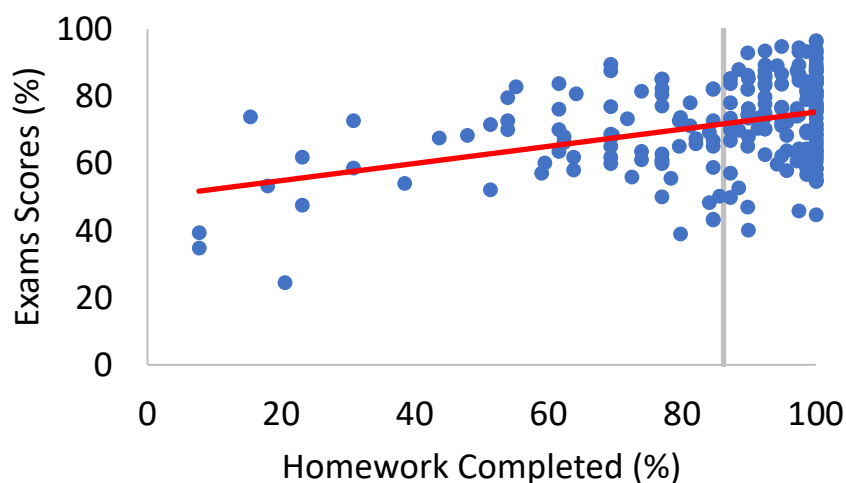


Figure 5. Correlation between the percentage of homework assignments submitted and exams scores in 3 offerings of a problem-solving course taught using the effort flipped approach.

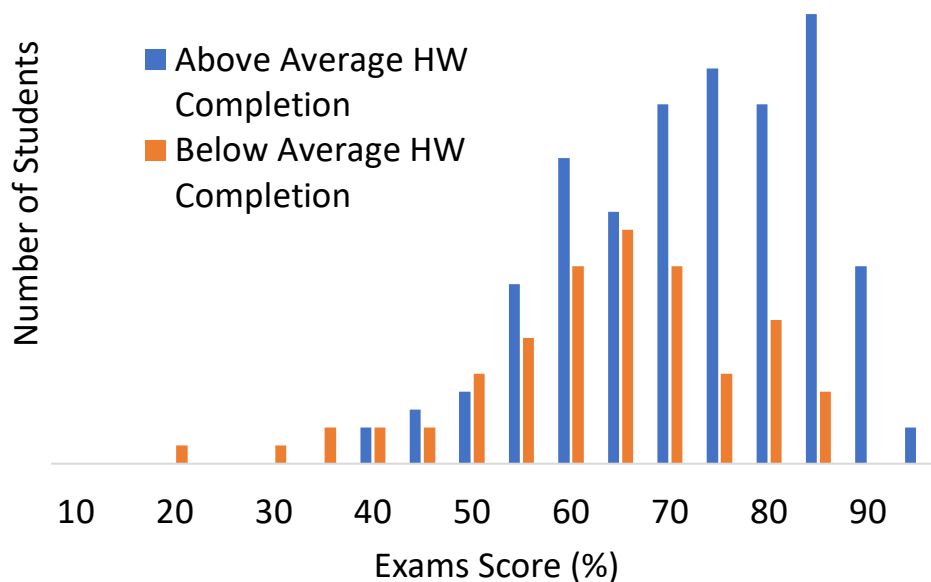


Figure 6. Comparison of the exams scores distribution of students who submitted an above average number of homework assignments to that of students who submitted a below average number of assignments for offerings taught using the effort flipped approach.

In the final phase of the present study the teaching approach was changed in two ways. The class remained flipped, and homework continued to be graded on effort, but problem type identification was taught explicitly and homework wrappers were assigned for each homework assignment. Also, during in-class problem solving activities, problem type identification and general problem solution methods were included in the scaffolded solutions. The assignment statement for a typical homework wrapper was as follows:

The identification of kinetics problems and a general procedure for their solution were described in class. In-class learning activities involving kinetics problems illustrate both the identification of kinetics problems and the implementation of the general procedure for solving them. Mastering these abilities will prepare you to be successful on exams. Compare your solution to AP 9 to the solution posted on [redacted] and to section II of the [redacted] Problem Types handout, and then write a brief (1 to 4 sentence) self-assessment of your identification of the problem as a Kinetics Problem and your formulation of a solution to the problem. If your solution was lacking, identify what was missing or incorrect and how your thinking was incorrect (e. g. didn't understand what the question was asking, didn't understand a concept, didn't understand how to implement a concept, made an improper assumption or simplification or applied concepts correctly but made a math programming error that caused the answer to be incorrect).

The use of homework wrappers did not appear to increase the amount of time necessary to complete an assignment. Homework assignments generally were posted a month or more before they were due. There was an assignment due at the start of most class meetings. It consisted of a wrapper for the previous assignment (one problem) and one new problem. The solution was posted online immediately following the class in which it was submitted. The wrappers were not considered in the effort-based grading of the homework assignments.

This teaching approach will be referred to as the wrapped effort-flipped teaching approach. The timing of the practice and feedback are not changed in this approach, as Table 1 indicates. All practice and feedback occurred prior to assessment. However, in addition to adding problem-type identification practice (both during in-class activities and in homework assignments) the wrapped effort-flipped approach introduced a second type of feedback. Specifically, the homework wrappers did not target identification of what the student did that was incorrect, but instead they were intended to cause the student to reflect upon why they had proceeded incorrectly. That is, the goal of the wrappers was to foster student self-analysis of their thinking as they solved the assignment.

Records for 267 students from 3 wrapped effort-flipped offerings of the course in 2015, 2017 and 2018 were examined. The class sizes ranged from 81 to 93, and the results are shown in Figures 7 and 8. The slope of the trendline in Figure 7 is 0.435 ± 0.05 , and the average percentage of homework completed was $87.1 \pm 1.0\%$. The average exams score of students who completed more than the average amount of homework was 77.5 ± 2.5 compared to 65.1 ± 4.6 for those who completed less than the average.

It should be noted that despite the changes to the teaching approach over the course of the entire study the overall average exams score and the percentage homework submitted were essentially constant. The average exams score over all 1307 student records was 74.08 compared to 74.67, 75.21, 71.79 and 73.45 for the traditional-lecture, traditional-flipped, effort-flipped and wrapped effort-flipped approaches, respectively. The average percentage of homework submitted was 87.75% compared to 88.04, 88.83, 86.19 and 87.09%, respectively. What did change were the trendline slopes and the exams scores distributions for students who did more vs. less than the average amount of homework. This is summarized in Table 2 which shows the trendline slopes and the difference in the average exams scores between those who completed more than the average amount of homework and those who completed less.

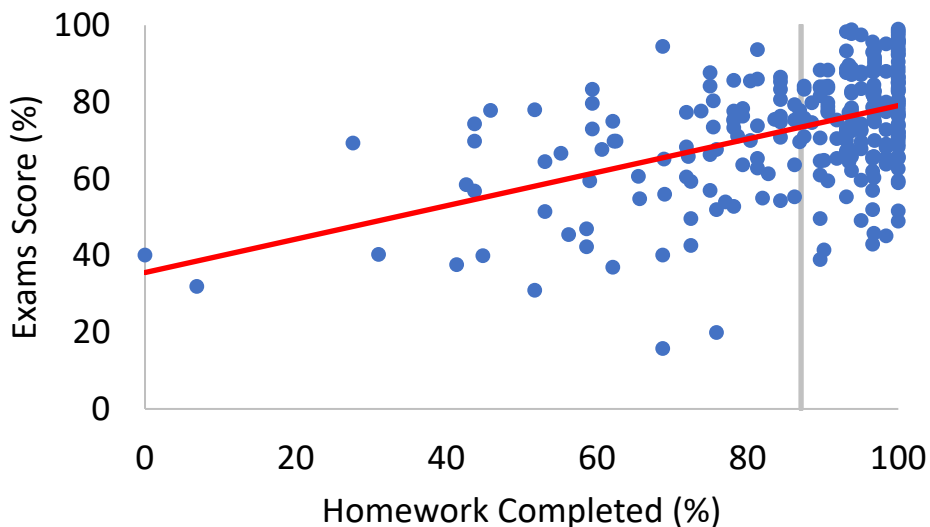


Figure 7 Correlation between the percentage of homework assignments submitted and exams scores in 3 offerings of a problem-solving course taught using the wrapped effort-flipped approach.

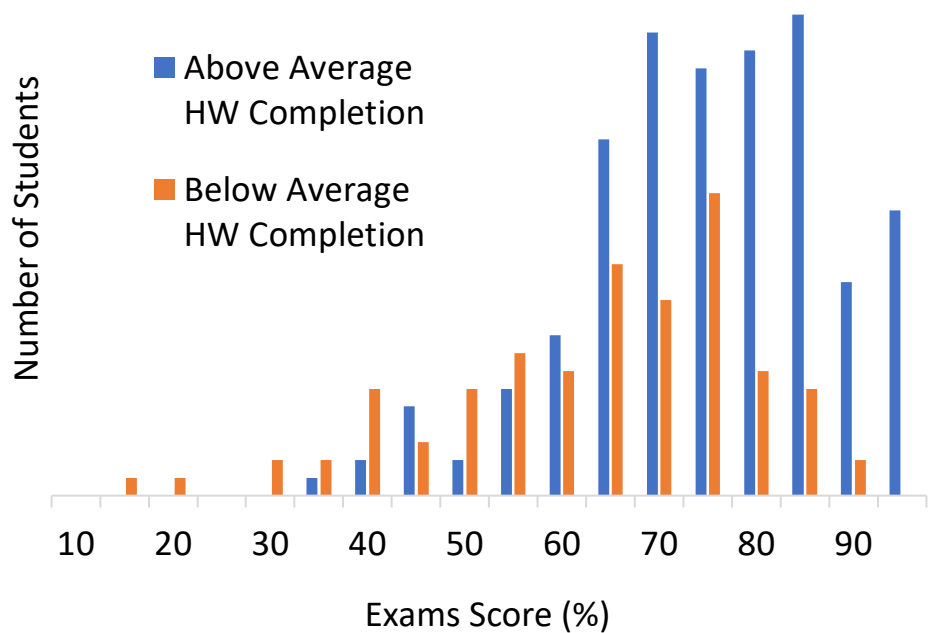


Figure 8. Comparison of the exams scores distribution of students who submitted an above average number of homework assignments to that of students who submitted a below average number of assignments for offerings taught using the wrapped effort-flipped approach.

Table 2. Effect of homework effort upon exams scores for different teaching approaches.

Teaching Approach	Trendline Slope	Exams Score Difference*
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Traditional-Lecture	0.171	1.43
Traditional-Flipped	0.287	9.27
Effort-Flipped	0.256	9.3
Wrapped Effort-Flipped	0.435	12.45

* Difference in average exams score of students who completed more that the average amount homework to those who did not

Discussion

Figures 3 and 4 and Table 1 show that after changing from the traditional-lecture approach to the traditional-flipped approach, homework completion had a much stronger effect upon exams scores. On average, the exams score of a student who completes *all* of the homework is 28.7 ± 3.5 points higher than that of a student who completes *none*; in the traditional approach the difference is 17.1 ± 3 points. The 1.5-fold increase in the trendline slope cannot be fully attributed to the uncertainties. The difference between average exams scores of those who did an above-average amount of homework and those who did not increased from a statistically insignificant 1.43 points to a significant 9.27 points. Examination of Table 1 shows that two aspects of homework and feedback were added through this change in teaching approach.

Both added practice and feedback characteristics are the result of in-class problem solving activities. The in-class problem-solving activities utilize problems of the same types and difficulties as those encountered on homework assignments and exams. The students do not submit their in-class solutions, allowing them to learn from their mistakes without a grade penalty. These activities provide an opportunity for the students to practice problem solving and to receive immediate mistake identification feedback before their learning is assessed.

The identification of mistakes feedback is received almost immediately so that they can correct those mistakes before proceeding. Automated homework systems are popular for the same reason. A significant difference is that in the flipped classroom, the instructor is present when these mistakes are made. If the students don't understand why what they have done is incorrect, or if they have misconceptions, the instructor is present and can offer explanation. Indeed, if the instructor observes multiple students making the same mistake or having the same misconception, the problem-solving activity can be paused while the instructor discusses the point with the entire class. In the traditional-lecture teaching approach, the only way for a student to receive similar feedback is to go see the instructor or a teaching assistant outside of class before the assignment is due. Even so, there is a delay between when the student made the mistake and when feedback is received.

In both approaches, the timing of the post-submission feedback was not uniform due to technology changes. Initially, homework was graded and solutions were posted on a bulletin board. The time difference between submission of an assignment and receipt of feedback was typically a week, but sometimes longer. In later course offerings, posting of solutions shifted to an online mode where the solution was available within an hour of submission, but grading still could take as long as a week.

Because two changes were effected at the same time (practice and feedback prior to assessment), it is not possible to gauge their relative importance. Similarly, it is not possible to assess the relative importance of the immediacy of the feedback. The magnitude of the differences between traditional-lecture and traditional-flipped in Table 2 is surprising. In both approaches, all homework assignments are the same with the practice occurring during assessment and with the feedback being received after assessment. It is only the in-class activities that add pre-assessment practice and feedback.

The change to an effort-flipped teaching approach in the second phase of this project provided the students with much greater opportunity to practice and fail without penalty. However, the type of feedback they received did not change. Examination of Figures 5 and 6 and Table 2 shows that this change did not affect the correlation between homework effort and exams scores significantly. The results are essentially the same as when the traditional-flipped approach was used. One possible reason is that the in-class problem solving activities provided sufficient pre-assessment practice and feedback that the additional pre-assessment practice and feedback obtained from the homework that was graded on effort only an incremental impact. An alternative reason is that the large change observed when the traditional-flipped approach was used is due to factors other than the changes in practice and feedback. The present data do not permit discrimination between these possibilities.

From a practical perspective, it is significant that the change to effort-based grading of the majority of the homework assignments did not lead to *decreased* exams scores. Grading assignments on the basis of effort greatly reduces the time it takes to grade an assignment. Using the effort-based grading scale described here, grading an assignment takes no more than a minute. As a consequence, the time spent grading, or the number of teaching assistants employed to do the grading, is decreased markedly with no observable effect upon learning outcomes.

The change to a wrapped effort-flipped format caused another favorable improvement in the correlation between homework effort and exams scores, Figures 7 and 8 and Table 2. There were two components to the change in this final phase of the present study. First, problem type identification and associated problem solution approaches were explicitly taught. Second, through the use of homework wrappers, students were asked to self-generate feedback on where their problem-solving thought processes were flawed. This metacognitive feedback is very different from the mistake identification feedback in all other teaching approaches, and it was provided in addition to the mistake identification feedback.

The overall effect of the wrapped effort-flipped approach is highly encouraging. The slope of the exams score vs. homework effort trendline increased 2.5-fold and the difference in exams scores for those who submitted more vs. less than the average amount of homework increased from 1.43 to 12.45. These changes are beyond the range of statistical uncertainty. It is important that the average percentage of homework submitted did not change throughout this study.

To date, this study has shown that certain changes to the teaching approach used in a problem-solving course can increase the effect of homework completion upon exams scores. These changes can be rationalized in terms of providing students with more opportunity to practice problem-solving and with better targeted feedback, but these explanations remain to be proven.

The next stage of the project will compare students' self-generated analysis of where their solution process deviated from the general solution approach to an expert's analysis.

Summary

It was observed that in a lecture-format problem-solving course, the amount of homework completed by students only had a weak effect upon exams scores. Three changes were made to the approach used to teach the course in an effort to increase the effectiveness of homework assignments. First the class was flipped so that in-class problem-solving activities could be used to provide practice and feedback to students prior to assessing their learning. Next, homework grading was changed from a correctness basis to an effort basis. Finally, the identification of problem-type was explicitly taught, allowing the use of homework wrappers. The homework wrappers asked students to reflect upon their thought processes at the time they solved each homework assignment, comparing it to the general approach they had been taught for that problem type.

After the changes were implemented, completion of homework was observed to have a stronger effect upon exams scores. The slope of the trendline in a plot of exams scores as a function of percent homework submitted increased from 0.171 to 0.435 after the changes in the teaching approach, and the difference in exams scores for those who submitted more vs. less than the average amount of homework increased from 1.43 to 12.45.

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