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Replacing Graded Homework Assignments in Statics

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Abstract

Innovation in Statics instruction is an important area of research with new approaches including: flipped classroom, concept mapping, on-line homework, and others. Most traditional teaching of Statics has involved a homework assignment where the students solve problems similar to those from lecture. The homework problems serve to reinforce the new concepts and to develop the students' ability to solve math and physics based problems. These homework assignments have also typically been graded student assessments.

The challenge with using these homework problem sets for student assessment lies in the difficulty in assuring that what is submitted represents the students' own work. As someone who has returned to teaching following a 20+ year hiatus in industry, one striking observation is how readily the solution manuals are available to the students and how automatic is their inclination to work together on assignments. One downside to these changes is that the students may too readily access the known solutions and not challenge themselves into the learning zone. Many of the students' homework sets resemble the solution manual. This makes grading the homework sets to have no value, either for providing feedback to the students or for assessing their learning. In this study, a different approach was taken. As in the traditional method, a weekly problem set was assigned from the textbook. In this case the students were encouraged to avail themselves of all relevant resources: solution websites, group work, faculty help, or other. The goal was for the students to understand how to solve the assigned problems. The assessment was changed from grading the homework assignments to one where an in-class quiz was given directly after the homework was turned in. One of the assigned problems was chosen and the students were assigned to solve it, in class, with no references. Since the selection of the quiz problem was not known ahead of time by the students, they had significant incentive to understand how to solve all of the assigned problems. The assessment rests on the graded quizzes with only a nominal weight given to whether the homework problems were submitted.

The preliminary evaluation of this approach was conducted in a Statics class section of 33 engineering students. Two assessment metrics were used. The first is the class final exam scores compared to previous sections taught by the same instructor. The second examines the submitted student homework and classifies whether the student had copied down a solution or shown evidence of working through the problem on their own. The quiz scores and final exams were then compared on this basis. Surprisingly, only weak relationships were seen between perceived student effort (working the problems or copying solutions) and demonstrated student understanding. The value to the students for working through the problems, even using solution manuals was measureable although not statistically significant compared to those who just copied down the solutions in a rote manner. From this it is inferred that there is benefit in copying out the solutions to worked examples. Implications for this approach are discussed and verification testing is proposed.

Background

In recent years there has been significant effort at reexamining the traditional approach to the foundational courses in the STEM curriculum. For a course, like Statics, there has been a pressing need to reform teaching methods and many studies have been undertaken to develop new approaches [1]-[8], [13]. In [1] a set of detailed references are given covering some of these new approaches, so will not be repeated in detail, here. Methods have been examined including: concept maps [2], [3], flipped classrooms [4], peer led learning [5], context rich learning [6], on-line homework and learning modules [7], adoption of Agile methodologies [8] and learning from worked examples [9]-[12].

The present study makes use of treating homework problems as worked examples, WE, rather than the more traditional solving problems, SP. There has been significant work in the use of WE and a number of accepted learnings has arisen. The mainstay approach of SP as the learning tool to accompany lectures has significant drawbacks for students new to a field of study. They typically will not be familiar enough with the subject matter to recognize the different schemas for the various classes of problems. There is cognitive overload [10] and the students expend considerable effort in searching for similar problems so they can borrow the approach for their current problem. This shortchanges the process of understanding the underlying theory and seeing its logical application play out. Once a student becomes more advanced in a field then they have a more developed perspective and can recall the problem class and not be overburdened with the large information gathering required by this approach.

The use of Worked Examples, on the other hand, presents suitably designed problems that are logically laid out from definition through solution. If such problems are carefully studied, then even the novice in a field can absorb the rate of new information and develop mental models for how such problems are approached. Cognitive Load Theory [13], [14] explains that too much burden can be placed on working memory when asking a novice in a field to directly solve problems without the framework and schemas for them. The observation has been made that learners with no previous problem-solving experience in the field under study learn better from worked examples than students who have mastered the principles in the subject [10]. This would seem to apply to most engineering sophomore Statics students. Specific factors have been laid out in the literature that can make this approach more, or less, effective. For example, the way the student self-explains through the solution of the worked example is important [9]. It is also important that the students study the example problems deeply and not just give a cursory reading [10] and several ways to approach this have been proposed for application to Statics including pairing like problems and having fading steps such as with partially-completed worked examples [13].

Motivation

The author recently returned to teaching after a 22-year hiatus working in industry. From 1993-1996, he had taught multiple sections of Statics at a large private university as a tenure track faculty member. In 2018, he again took up academic pursuits, this time at a smaller, private, military college, also teaching Statics. Although the subject matter had not changed and mainly revision updates had been made to textbooks, one stark difference was the availability of the solutions for all of the homework problems from the standard textbook. The author observed that many of the submissions to the weekly homework assignment bore very close resemblance to the solution manual. Evidently, through online resources, the solutions are readily available and many students avail themselves of them. In addition to the frustration of being unable to rely upon homework as a reliable assessment of student learning, the question arose of whether "copying of the solution" provided an effective learning experience.

The first year back teaching was conducted in a traditional way: 3x/week 50 minute lectures, a weekly graded homework assignment of 5-6 problems taken from the textbook, 4 one-hour exams, a computer analysis project, and a final exam. The graded homework assignments constituted 20% of the final grade.

For the second year, a different approach was taken to the homework, largely driven by a desire to have a better assessment of the student's progress. As before, 5-6 homework problems were assigned each week from the textbook. The students were told that they could use whatever aids or help was needed to solve the problems and that they would need to turn in the written solutions each week. It was explicitly indicated to them that online solutions, working together in groups, or seeking assistance from the professor were all acceptable guides to solve the problems but that they should not copy each other's work. The students were encouraged to first try to work the problems on their own but that seeking other help was acceptable.

For each weekly homework set, one of the problems was selected and given as a short, closed book, in-class quiz. The students submitted their paper copy homework at the beginning of the class period and then the whole class was given the same problem, as a quiz, with about 10-15 minutes to solve. The students knew that they would be getting one of the homework problems as a quiz but they did not know which problem it would be. The hope was that the students would not just copy the homework solutions since they might need to know how to solve each and any of the assigned problems. It was felt that the students could not easily memorize the solution steps for this many problems so that acquiring an understanding of how to approach the problems would occur. The quiz grades were used as the assessment of the ongoing learning and 25% of the course grade came from these quizzes. A separate homework grade was also given which constituted 5% of the final course grade. The homework was just checked off to see that it was done. The final homework grade was just the ratio of submitted homework assignments out of the total number given during the term (11). The 5% contribution to the final grade was chosen to provide some incentive for the students to work the problems but the real payoff was to understand how to solve them for the quizzes, since they counted for 25% of the final grade.

The study reported here, sought to compare the quiz grade, as a measure of learning, with the approach and effort that the student had put in to the homework assignment. Since the homework was submitted, the professor was able to assess how closely the work resembled the solution manual provided by the publisher and infer whether the problem solutions had been copied down in a rote manner or whether the students had shown their own attempts to solve it, as well. The quiz grades were compared, based upon this assessment, to determine if copying down the solutions provides a sufficient learning experience to be continued for future classes. It is important to note that the quiz problem each week came from the list of problems that the student had just solved. It was not intended to measure how the students' abilities translated to solving different problems but whether they really knew how to solve the homework problems and did not just succumb to rote copying.

An attempt was made to infer how the approach that the student took to their homework assignment translated into holistic learning by comparing final exam scores with their average homework categorization score.

Methods

During the course of the semester, the instructor captured images of six of the submitted homework problems. A total of 11 homework assignments and quizzes were given across the 14-week semester and these six problems were chosen as a representative sample spread across the term. They covered the topics shown in their chronological order in Table 1.

Table 1. Topics for Homework Problems/Quizzes Used in Current Study

Quiz Designation	Problem Topic
A	3D Moment Calculation
B	Equivalent Force-Couple
C	Method of Sections
D	Shear Force/Bending Moment
E	Friction
F	Composite Centroid

Once the semester had ended and the final grades had been submitted, the instructor analyzed the submitted homework solutions and then compared them with the quiz scores. The University's Institutional Review Board wanted the instructor to make certain that this analysis was not conducted until after final grades had been assigned and so could not influence the instructor in the grades given for the course. During the analysis each of the homework problems was compared with the publisher's solution manual and with a popular internet supplier of homework solutions for common textbooks [15]. The student's homework problem approach was classified into one of 3 categories.

- Category 1: Evidence in the student's solution that they worked independently of the published solutions. Additional detailed work or a different approach was evident. For example, in both published solutions for Quiz C, the moment was calculated about a certain joint but in some of the students' work, a different joint was used for the moment calculation. Also, student work that gave the incorrect numerical result was also categorized here.

- Category 2: The student approach followed very closely with one of the published solutions but some differences, most often additional steps filling in more detail, was present. It appeared that the student was guided by a published solution but was also working the problem as they went and so not just copying it down.
- Category 3: Evidence that the student followed very closely the published solution and copied it down without working the problem themselves. Very often the layout by the student mirrored exactly the published solution. When there was an exact copy or only a single substitution of a variable name for its numerical value, or vice-versa, the problem was categorized here.

The flow chart that guided these classifications is shown in Figure 1.

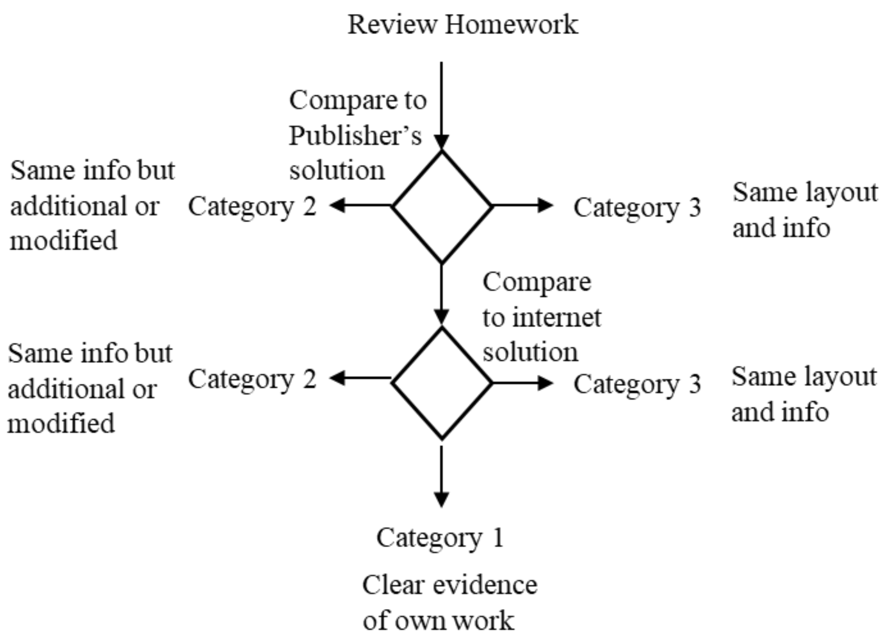

Figure 1. Flow chart for categorization of homework problems

Once the homework problem was categorized, it was compared with the scores obtained for that problem given as an in-class quiz. The quiz scores were collected by homework categorization and examined for correlation regarding the efficiency of using the published solutions in preparing for the quiz.

Finally, the impact on final exam scores were examined in three ways. First, by comparing them based upon the student's quiz scores to assess whether the quizzes, in the ways that they were administered, correlated with the overall student learning. Second, the final exam scores were compared with the average homework categorization for each student to determine whether the approach to homework carried through to overall learning, Last, the final exam scores were compared to those from a previous section of Statics, taught by the same faculty member which had homework in the traditional graded problem methodology.

Results and Analysis

The categorization of the submitted homework problems was completed before the quiz scores were consulted. The categorization was carried out by comparing the student's work with printed copies of the solution from the publisher's solution manual and one extracted from the website [15]. The class consisted of 33 students (28 male, 5 female). Two students had additional time accommodations for exams but did not make use on the quizzes. Since the university is a military college, a significant percentage of the student population is in the Corps of Cadets. This means that they live together in "barrack" dormitories, have military style training and activities, and wear military style uniforms to class. Twenty-two students, or 67% of the class was in the Corps of Cadets. This ratio mirrors the university as a whole. The class had limited racial diversity with only one African-American and one student from Africa.

The overall categorization of the Homework problems is shown in Table 2. Note that even though 33 students were registered for the course that on any given week only 25 to 30 both turned in homework and were present to take the quiz. At the university, attendance is taken at class and the students are allowed to miss lectures totaling 2 weeks' worth of meetings over the course of the semester.

The homework breakdown shows some immediate points. The number of homework problems categorized by the fidelity paid to the published solutions is not constant but varies by problem. For example, the number of problems categorized as 3 (reflecting virtual copying of solution manual) varied from a low of 31% (8 out of 26) on Quiz F to a high of 74% (20 out of 27) on Quiz C. The overall grand average shows that 55% (90 out of 162) were Category 3 across all of the problems. The number of category 1 solutions was greater toward the end of the semester. This may be due to the subject matter being perceived as more straightforward by the students or their becoming more comfortable submitting homework problems that might have incorrect answers.

Table 2. Summary of Homework Categorization

Quiz Designation	Problem Description	n	Homework Category 1	2	3
A	3D Moment Calculation	**30**	**4**	**12**	**14**
B	Equivalent Force-Couple	**25**	**2**	**5**	**18**
C	Method of Sections	**27**	**1**	**6**	**20**
D	Shear Force/Bending Moment	**28**	**3**	**7**	**18**
E	Friction	**26**	**7**	**7**	**12**
F	Composite Centroid	**26**	**7**	**11**	**8**
	Total	162	24	48	90

It is also striking that category 1 had the fewest number of problems. Categories 1 and 2, taken together, can be viewed as demonstrating that these students did not just copy down the readily available solution but showed some evidence that they were thinking about the problems and personalizing their work on them. In the roughest sense then, we can say that, on average a little more than one-half of the students may have just copied down the answer, but the other, almost one-half, showed evidence of working the problem with more, or less, guidance from the published solutions.

From the perspective of student learning, does it matter? Do students learn better by attempting to work problems themselves or by reading and copying down a correct solution? In this study the students were not pre-selected to a certain homework approach but they self-selected. The categorizations may reflect learning style differences. In future studies a separate learning style assessment would be interesting to compare with homework category approach. Another inquiry that could also be interesting would be a breakdown of the time that the students put into homework. Did those who used category 3 take advantage of added time for other studies such as on-line videos or reviewing additional problems? The literature on learning by worked examples has been briefly discussed. Now turn attention to how well either way prepared the students to demonstrate their learning on the quizzes.

Each quiz problem was graded out of 20 points with typically one-half of the points for demonstrating the correct understanding of the principle (and equation) at work and one-half of the points for the reduction to the correct answer. The quizzes were graded and returned to the students during the semester and only after the term ended were they compared with the categorization of that homework solution submitted by that student. The results of the quizzes by categorization of the corresponding student's homework solution are shown in the following tables.

Table 3. Average Scores for Quiz A (out of 20 points) by Homework Category

Homework Category	Quiz A Average	Quiz Std Dev	n
1	14.75	3.77	4
2	17.08	3.23	12
3	16.29	3.54	14

Table 4. Average Scores for Quiz B (out of 20 points) by Homework Category

Homework Category	Quiz B Average	Quiz Std Dev	n
1	15.50	6.36	2
2	18.80	1.30	5
3	15.33	3.93	13

Table 5. Average Scores for Quiz C (out of 20 points) by Homework Category

Homework Category	Quiz C Average	Quiz Std Dev	n
1	17	NA	1
2	14.67	4.59	6
3	10.59	3.89	20

Table 6. Average Scores for Quiz D (out of 20 points) by Homework Category

Homework Category	Quiz D Average	Quiz Std Dev	n
1	19.33	1.15	3
2	17.29	4.42	7
3	16.61	3.71	18

Table 7. Average Scores for Quiz E (out of 20 points) by Homework Category

Homework Category	Quiz E Average	Quiz Std Dev	n
1	15.71	5.19	7
2	10.86	5.61	7
3	14.00	4.37	12

Table 8. Average Scores for Quiz F (out of 20 points) by Homework Category

Homework Category	Quiz F Average	Quiz Std Dev	n
1	18.29	1.70	7
2	19.55	1.04	11
3	19.00	2.45	8

Some interesting trends can be noted by examining the average quiz score for each category. For most of the Quizzes, the highest average scores were for those who had shown homework evidence of Category 2. This makes sense since the students showed that they were following along and adding to or at least understanding the published solutions. The number of students who worked apart from following the solution manual was quite small so it is hard to draw strong conclusions but on two of the quizzes (C and D) they performed the highest, albeit with only 1 and 3 students. The anomaly is Quiz E, which was on Friction. On this problem, alone, those whose homework was categorized as a 2 had the lowest average quiz scores. This is a bit perplexing but fewer of these were categorized as 2s and more of these were categorized as 1s than typical. It might be that the categorization process was not as robust for this problem. Certainly, having the published homework solutions available to the students did not disadvantage them in learning the material, as long as they put in the effort to understand and work through it.

Statistical comparisons were made between Categories 2 and 3 for each Quiz set using the Microsoft Excel function “t-Test: Two-Sample Assuming Unequal Variances.” Although there were consistent numerical differences in favor of Category 2 these were not statistically significant with the exception of Quiz B, the Equivalent Force Couple System. Here the quiz scores for students whose homework was categorized as a 2 (18.80) was significantly higher than those of Category 3 (15.33) with a p-value of 0.0048 .

The overall weighted average of the scores by homework category was determined by combining all 6 quizzes is given in Table 9. This clearly shows a numerical gap between the performance of the students who tried to work the homework problem and those who regurgitated the solution manual.

Table 9. Grand Average for Combined Quiz Scores

Homework Category	Grand Average	n
1	16.79	24
2	16.65	48
3	14.80	85

It is clear that the students who showed evidence of working through the homework problems (whether closely guided by the solution manual, or not) did numerically, although in general, not statistically, better at solving the same problem in a quiz format than those who had just copied the solution manual. No average numerical difference was observed between those who seemed to be guided by the solution manual in solving the homework and those who worked more independently. Certainly those who were guided by the solution manual did not show evidence of being disadvantaged relative to those who did not.

The comparison was also made to see if the approach to homework showed a correlation with final exam scores. The individual students did not always receive the same homework categorization for each assignment. An average of the scores for the homework assignments that were evaluated was taken as an indication of that student's approach to their homework. Since several of the students only submitted a limited number of the homework assignments, they were eliminated. The correlation was examined for those who submitted at least 4 of the 8 evaluated assignments. Figure 2 displays the plot of these data.

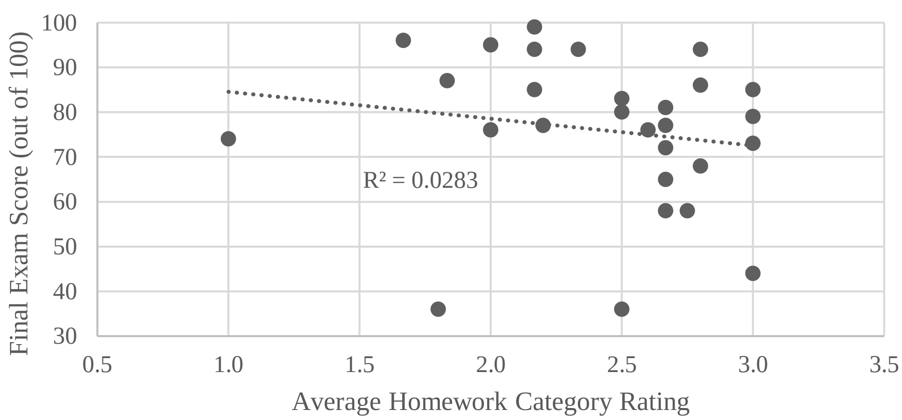

Figure 2. Comparison of Final Exam Scores with Average Homework Categorization

The results show that the final exam scores ranged from 36 to 99, out of 100 points. Notice that there is no discernable trend with a very low correlation coefficient. Since the trendline can be strongly influenced by the single data point at the Category Ratio of 1.0, a comparison was made between the Final Exam Scores for the Average Categorization of 2.5 and above versus that between 1.5 and 2.5. The results are shown in Table 10.

Table 10. Average Final Exam Grades by HW Categorization

HW Ave Categorization	**n**	**Final Exam Average**	**Std Dev of Final Ave**
> 1.5 and < 2.5	10	83.9	18.6
>= 2.5	17	71.5	15.3

There is a large difference in the final exam average for those whose HW categorization centered around 2 (showing use of solution manual to guide working through the problems) as higher than those with HW categorization nearer 3 (copying down of solution manual). This difference is perhaps meaningful but it is not statistically significant ($p=0.093$) due to the large variance within both groups. As might be expected, the trend favors those who put in the work to make the problem solutions their own but the trend is not strong enough to be statistically significant. Although detailed working of the problems is advantageous there is still benefit to just copying down the correct solutions such as the Worked Example approach.

The question of whether the Quiz conducted as in this study provides a meaningful assessment of the students' ability to solve problems that they have not already studied was examined by comparing the student's average quiz score with their final exam score. As seen in Figure 3, there is a general trend of higher Final Exam scores going to the students with the higher Quiz Scores. The correlation coefficient of 0.67 demonstrates a relatively weak correlation, but one that is logical, nonetheless. This can be taken as confirmation that the use of the quiz, in the manner used here, has value as a leading indicator of the student performance.

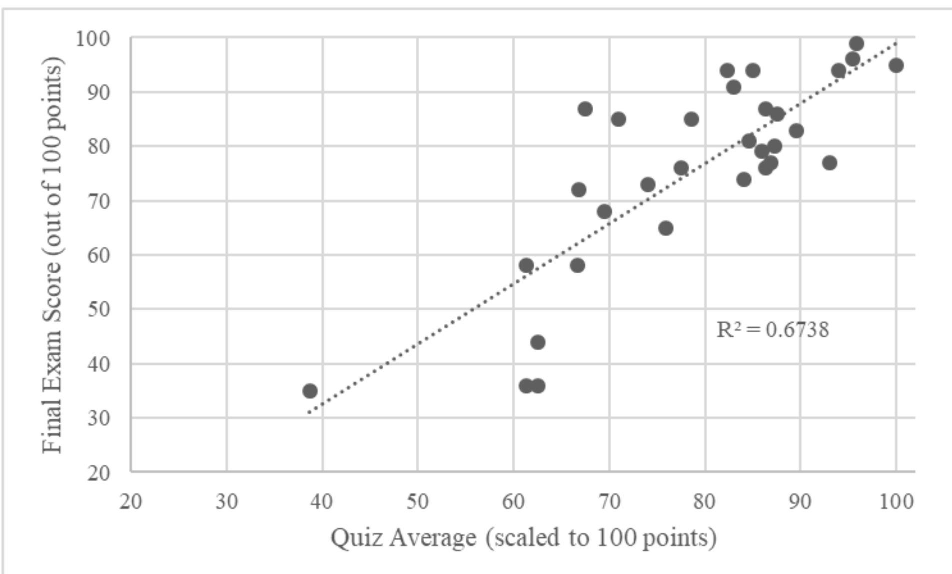

Figure 3. The Average Quiz Score Correlation with the Final Exam Score

The final result came from comparing the final exam scores for this section with a similar section taught by the same instructor during the previous year. This previous section assigned a weekly homework problem set that was graded and no weekly quiz was given. This was viewed as the Traditional teaching method. The results are listed in Table 11. The final exam for both sections did not use the exact same problems but ones that were very similar. The final exam averages were very close with no statistically significant differences between them. From this it is not clear that, on average, the teaching approach gave better results but there is also no evidence that encouraging the students to make use of problem solutions put them at a disadvantage. Perhaps there is a clue in the larger standard deviation in the new teaching method that the students have the opportunity to get more out of the class if they put more into the class.

Table 11. Comparison of Final Exams from Different Sections

Teaching Approach	Final Exam Average	Standard Deviation	n
Traditional Problem Solving Homeworks	76.8	11.3	20
Ungraded Homework Plus Graded Quiz	75.5	18.1	31

Conclusions

The approach taken during this course can be viewed as an indirect application of Worked Examples in place of the traditional Problem Solving homework methodology. The results indicate that there is a numerical advantage for the students who put in the effort to solve the problem as guided by the given solution rather than just copying the solution down. This is consistent with the literature observation that Worked Examples should be carefully studied in order to get the most benefit [10]. All of the students in the class had an extrinsic motivation to carefully study the problems since they would be quizzed on one of the problems but fewer than one-half of the submitted homework samples exhibited clear evidence of careful study. The challenge for the instructor is to help all of the students put in this careful study. Some approaches could include; increasing the percentage of the final grade that comes from the quizzes, taking points from the homework score for evidence of rote copying, assigning original homework problems for which there is no solution manual available to the students, and assigning partially-completed problems that the students need to complete [13].

The use of a quiz which asked the students to solve, in closed-book fashion, one of the homework problems which they had just submitted provided an appropriate measure of the students' on-going learning. Both the approach that the students took to the homework and their quiz scores had a weak correlation to the final exam scores.

The results of this study indicate that the students are not disadvantaged by having the homework solutions available but that their effort in working through the solutions of the problems is a key to their best performance. A follow-up study with randomized sections of students comparing the current approach of solved problems against one with original problems for which no solution manual is available could add some robustness to these observations.

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