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Work-In-Progress: Changing the Goal Structure in a Problem-Solving Course

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This study is examining pedagogic practices for increasing the effectiveness of homework problems in post-secondary problem-solving courses. For present purposes, a problem-solving course is one wherein the instructor presents theories, derives and simplifies equations, and shows how to use them to answer questions about a particular process or system. The learning outcomes of the course then center around the learner being able to formulate and solve equations to answer a variety of questions about systems or processes to which the theory applies. The context of this study is an upper-division chemical engineering course on kinetics and reaction engineering at a large university in the northeastern U.S. This course is a prototypical engineering problem-solving course.

Achievement goal theory [1-5] is being used to frame this study. Very briefly, achievement goal theory posits that students perceive a goal structure based upon the course environment, that the goal structure they perceive influences their achievement goal orientation, and that their goal orientation affects the learning strategies they employ [2, 6-9]. The four types of achievement goals are mastery-approach, performance-approach, performance-avoidance and mastery-avoidance [10, 11]. Mastery-approach goals involve <u>*developing competence*</u>; in a problem-solving course mastery-approach goals would be knowing how to solve problems. Performance-approach goals involve <u>*demonstrating competence*</u>; in a problem-solving course, performance-approach goals would be getting the correct answers to the questions. A mastery-approach goal orientation is positively associated with adaptive learning behavior and deeper learning [1, 6, 12]. For this reason, instructors seek to create a course environment wherein students perceive a mastery-approach goal structure.

Homework problem assignments are extremely common in problem-solving courses. Commonly, they are assigned regularly throughout the semester and graded on the basis of obtaining the correct answers. Typically, the grades on homework problem assignments constitute a fraction of the overall grade for the course. We hypothesize that the emphasis on getting the correct answer and including the homework grades as part of the overall course grade make performance-approach goals salient. Witness what we refer to as students' mimicry approach to solving homework problems: read the assigned problem, locate a solved problem that appears to be similar, and mimic (or worse, copy) the steps taken in that problem to obtain an answer for the assigned problem. This approach can be maladaptive: while they get the correct answer, they may not be able to do so on an exam where they don't have a solved problem to mimic. Our intention is to create a course environment where students perceive a mastery goal structure and adopt a mastery goal orientation when solving homework problems.

Specifically, we made five pedagogic changes to the course environment to make mastery goals salient. We call the first change "mastery coaching" [13]. It involves regular statements by the instructor that students should attempt to solve every problem using only a provided course equation summary, that getting stuck when solving a homework problem is good because it identifies a concept that they have not yet fully mastered, that on an exam, they won't be able to mimic a solved problem so they should practice solving problems under exam-like conditions, etc.

The second change is exposing expert thinking. Sometimes when expert instructors show learners how to solve a problem, they very clearly demonstrate ***what*** to do and ***how*** to do it. If, at the same time, the expert instructor does not explain ***how they knew what to do***, that is, if they don't explain the reasoning that led them to do what they did, then when students try to solve a similar problem, they won't know how to begin or proceed. To address this, we added explicit instruction to the course on how to identify and differentiate between different types of problems and then described a general approach for solving each type of problem.

The third change was the introduction of scaffolded, in-class problem-solving practice [14]. The course is delivered in a flipped format. The majority fraction of class time is spent on problem-solving activities. During these activities, the students are encouraged to work with classmates, and the scaffolded presentation of the problem solution leads them step-by-step through the identification of the problem type and the execution of the general approach for solving that type of problem. As additional problems of that type are solved in subsequent classes, the scaffolding is gradually removed. Throughout these problem-solving activities, mastery coaching is provided and expert thinking is exposed.

The fourth change was to grade almost all homework assignments on the basis of effort [15]. The students were told repeatedly that the purpose of the homework was for them to practice solving problems and to identify misconceptions and knowledge gaps. It was pointed out that if they know how to solve a problem, then getting the correct answer follows naturally. In fact, the solution to the homework was provided at the time it was assigned. Students were instructed not to mimic or copy it, but only to refer to it if they got stuck while solving the problem and then to compare their solution to it as they answered the associated wrapper question, see below. (It must be noted that after several opportunities to practice solving a particular type of problem, the students were assigned problems where they were graded upon obtaining a correct answer.)

In effort-based grading, each practice assignment was worth between 2 and 4 points. One point was awarded if the student attempted to set up equations to solve the problem (the point was awarded whether or not the equations were correct). A second point was awarded if the student attempted to perform the calculations using those equations as evidenced by a spreadsheet or Matlab code (again the points were awarded whether or not the correct answer was obtained). Many practice assignments included a "wrapper" question, see below. Students earned a third point if the wrapper question was answered. Some problems also included a "thought" question that asked them to interpret an answer on a physical basis or predict the effect of changing a problem parameter. Students earned a point if they answered this question; again, they earned the point even if their answer was not correct. The students' overall effort-based score on all such practice assignments counted as 20% of their overall course grade.

The fifth change was the use of wrapper questions [16]. Wrapper questions asked the students to reflect upon their problem-solving mastery for the current type of problem (whether it is improving, what they might do to increase it, etc.) and to use the provided solution to the problem to identify concepts that still were not clear to them and take corrective action. To date, we have not provided feedback on students' wrapper responses because we were still refining the wording of those questions, but we plan to start providing feedback on wrapper responses the next time the course is offered.

For each course offering, the fraction of the assigned homework that was submitted was recorded for each student. The percentage of possible exam points was also recorded for each student. The former was used as a measure of homework effort. Though arguably not ideal, the latter was used as a measure of attainment of course outcomes. The data from before the pedagogic changes (N=452, 10 course offerings) were analyzed separately from the data from after the changes (N=267, 3 course offerings). For each data set, a scatterplot was created, a linear least-squares trendline was fit and the average homework effort was computed. The results are shown in the upper part of Figure 1 (R^2 = 0.057 before changes, 0.233 after). Each of the two data groups was further grouped into homework effort above the average and homework effort below the average, and the distributions of exam scores for each group are shown in the lower part of Figure 1. Before discussing the results, it is important to note that the introduction of effort-based grading of homework assignments apparently did not affect homework effort; before the pedagogic changes the overall average homework submitted was 88% and after the changes it was 87%.

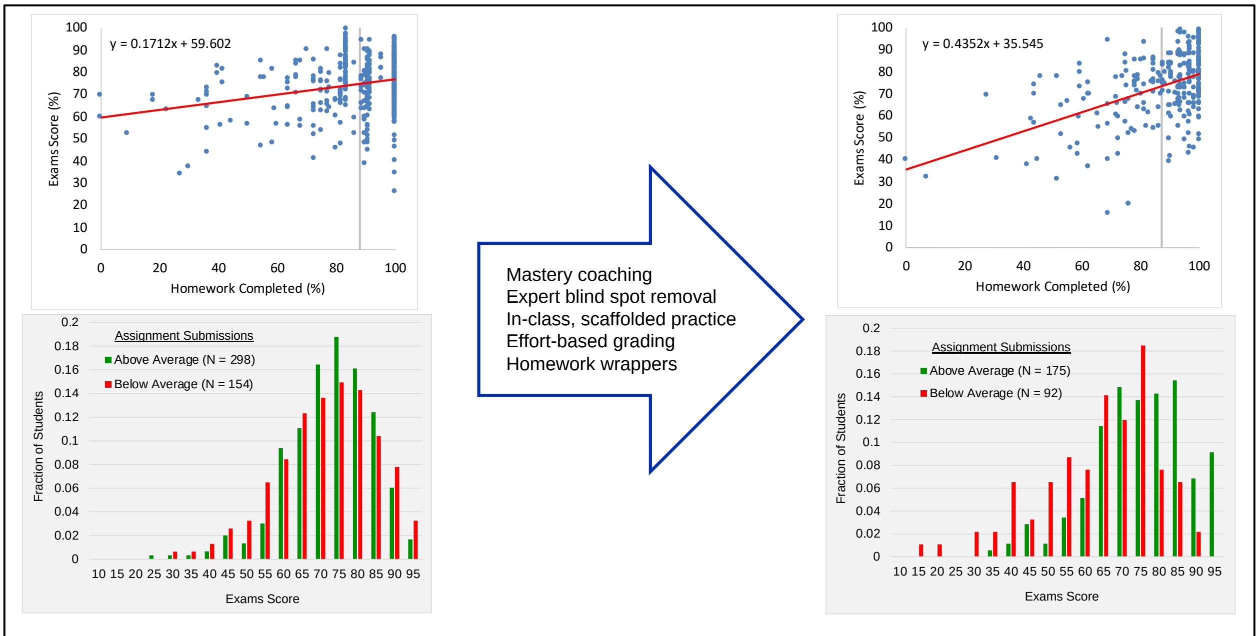

Figure 1. Scatterplots (top) showing association between homework effort and exams scores before (left) and after (right) five changes in pedagogy (center). Corresponding histograms (bottom) show exams scores for above-average (green bars) and below-average (red bars) homework effort. The red lines in the scatterplots are the least-squares trendlines and the gray lines indicate the average effort.

The upper scatterplots in Figure 1 show a positive association between homework effort and exams scores. Using the trendlines shown in red, the average effect of homework effort on course grade before and after the changes can be compared. Before the changes a 10% increase in homework effort resulted, on average, in a 1.7% increase in exams scores whereas after the changes, the same increasing in effort yielded, on average a 4.4% increase in exams scores. The lower histograms in Figure 1 each compare the distributions of exams scores for students with above average homework effort (green bars) to students with below average homework effort (red bars). Before the pedagogic changes, the distributions were statistically the same (Kolmogorov-Smirnov, $p > 0.05$) for below- and above-average homework effort. After the pedagogic changes the exams scores distributions are no longer equal (Kolmogorov-Smirnov, $p < 0.05$) with the distribution for above average effort shifted toward higher exams scores.

The results show that after the pedagogic changes, homework was more effective than before the changes. There was a stronger positive association between homework effort and meeting course learning outcomes. We attribute this change to a shift in students' goal orientations toward mastery approach goals. We believe that at the start of a problem-solving course, students hold performance-approach achievement goals as a result of their experiences in previous problem-solving courses. Indeed, they may believe that homework is not intended to provide an opportunity to practice and learn, but instead that its purpose is to assess learning.

The performance-approach goal orientation may be strongly held at the start of the course. Mastery coaching is expected to show students that homework can be a learning experience and to encourage them to view it as such. Exposing expert thinking equips students with an idea of where to begin and how to proceed, and thereby it reduces the need to rely on mimicry. Through scaffolded in-class practice, students learn how to identify a problem's type and apply the general approach for solving it, but in addition they experience how getting stuck identifies a concept they haven't fully mastered. The effort-based grading frees the students to use the assignments to develop problem-solving mastery without the pressure and worry of getting the correct answer. The wrappers reinforce the importance of using homework to learn how to solve problems instead of proving that they can do so, and they encourage the students to monitor and address their problem-solving mastery.

As a result, we expect that over time in the course, students' goal orientations shift toward mastery approach, and that shift is responsible for the observed increase in homework effectiveness. In the next phase of this project we will use survey instruments to measure the goal structure students perceive and the goal orientations they adopt as they progress through the course. At the same time we will quantify mastery coaching, expert thinking exposure, in-class practice, effort-graded practice and homework wrapper events over time. Using the resulting data we will be able to answer three important questions. 1. What goal orientation do students hold and what goal structure do they expect at the start of classes? 2. How, if at all, do the perceived goal structure and goal orientations change over time in a class employing the specific pedagogic components used here? 3. Are there positive associations between cumulative pedagogic events over time and goal structure/orientation over time?

The present results are consistent with the hypothesis that the five pedagogic changes shifted students' goal orientations, but they do not show causality. Answering these questions is essential for the practical application of achievement goal theory. To our knowledge, the evolution of goal structure, goal orientation and learning behaviors over the duration of a single semester has not been studied. Understanding of the dynamics and factors that affect that propagation is particularly critical for higher education where classes typically meet for only ~3 hours per week over a span of ~15 weeks.

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