Developing Problem-Solving Skills in Dynamics: Implementation of Structured Homework Assignments

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Abstract

Improved student learning should be a common goal for all instructors. Two objectives were 
explored in this study. First, we examined the impact of utilizing structured homework assignments, 
compared to online homework, on students’ learning based on concept inventory data and performance on 
test questions mapped to learning objectives. Second, we examined the effect of the homework system 
type on the students’ satisfaction and the attributes of their learning experience using a student survey. 
These data were collected in two consecutive semesters (Spring 2017: 42 students, Fall 2017: 58 students) 
of a required undergraduate dynamics course which utilized an online homework system and a structured 
homework system, respectively. Student learning data and survey data were analyzed to compare across 
semesters. Learning objective data demonstrated both improvements and declines in our students’ ability 
to solve problems and concept inventory data demonstrated an increase in the effect size in the structured 
homework system compared to the online homework system. Survey results showed that students in the 
structured, compared to the online homework semester, were more likely to complete their homework and 
retain their solutions. They also reported more confidence in their ability to correctly set up a new 
problem, in knowing the steps to solve the problem, and in getting the correct answer. These students 
were less likely to “google it” or look for the solution online. Our results confirm that there are trade-offs 
when selecting either a structured or online homework system. The design of a hybrid homework system 
is discussed and is currently being tested.

Introduction

Homework is generally accepted as an important part of students’ learning process. The general goal 
of STEM courses (e.g. math, physics, and engineering) is to develop the average student’s understanding 
of concepts to the level of either “applying” or “analyzing” on Bloom’s Taxonomy [1]. This goal is often 
achieved by developing the student’s ability to solve problems [2]. Concepts are more deeply understood 
by applying them to solve problems in a variety of contexts. Therefore, textbooks typically contain a 
significant number of example problems and practice problems, instructors utilize class time to work 
through example problems, homework often involves the student practicing problem solving skills, and a 
significant amount of tests and final exams are typically devoted to assessing the student’s ability to solve 
problems. Instructors typically agree that homework is an effective tool to help students develop a higher 
level of understanding of the concepts on Bloom’s Taxonomy and to develop effective problem-solving 
skills. Assessing student learning involves assessing both the student’s understanding of concepts (via 
concept inventories) and problem-solving skills (via tests and exams).

Solving problems as homework outside of class provides the student the opportunity to continue the 
learning that began in the classroom [3]. For example, homework may require the student to complete 
work that was started during class or to review concepts covered during class. The end goal is for the 
student to develop a higher level of mastery of the concepts by applying them in new contexts presented 
in homework problems. Homework presents other benefits as well. For example, writing out the solution 
to homework problems is an opportunity for the student to develop technical communication skills. 
Presenting problem solutions in a clear and concise structured manner is an important skill for the student 
to develop. This provides an opportunity to practice the language of the scientific method including 
specifying the knowns and unknowns, the assumptions and the applicable principle(s), the solution, an
interpretation of the results, and a discussion on the accuracy and the recommendations for further study. Working homework problems outside of class, whether done individually or in a study group, is also an opportunity for the student to engage in a self-evaluation of mastery of the concept and whether additional help is required to develop the expected level of mastery.

Learning is enhanced when homework is goal-directed, appropriately challenging, and targeted feedback is provided [4]. The goal may initially be focused on one component of the concept, but as a deeper level of understanding is developed, should include multiple components. Enough time, often in the form of repetitive exposure to the concept and/or attempts at solving problems involving the concept, is needed to develop an in-depth understanding of the concept. Unfortunately, both faculty and students tend to underestimate the need for practice. Two features of feedback on homework performance are accepted as being important to help the student’s learning. First, the feedback needs to communicate to the student where they are in terms of the stated learning objective and the method they should use to improve. Second, the feedback should be provided when the student can utilize it to enhance learning of the concept being studied.

Research on the benefits of online homework versus traditional homework (i.e. paper and pencil) is mixed and varied, at least in the context of using student grades to assess the difference [5]. Some have found that online homework, compared to traditional homework, has better student learning outcomes [6-9], while others have found no difference in outcomes [2, 10-13]. Even so, there is evidence of a difference. For example, Davis et al [14] points out that online homework software does not instill the importance of presenting a logical and organized solution. Davis et al. [15] found a strong and significant correlation between how students present their work and if problems are solved correctly, suggesting that online homework software may not help develop the student’s technical communication abilities. A synthesis of fifteen studies showed a positive effect on student learning when homework is both graded and feedback is provided [16].

The authors experimented with a structured homework system in a required dynamics course for mechanical engineering students. This course typically has 40-90 sophomore and junior level students enrolled and has been taught in a flipped format, using the SCALE-UP model [17] and Team-Based Learning [18] for several semesters. For many semesters, the instructor has utilized an online homework system. Recently, the instructor wondered about the impact of the online homework system on the student’s understanding of the concepts and on their ability to apply the concepts when solving problems.

The online homework system, while convenient for the instructor (automatically assigned, graded, incorporated into the learning management system) and with desirable options (randomized numbers, rapid feedback of performance, and multiple attempts), seemed to have unintended side effects on how students were approaching the homework. For instance, students rarely had collections of their homework solutions, which in previous offerings of the course were a major component of their study material for exams. Additionally, the homework system encouraged a focus on obtaining the correct numerical answer, with no value attached to the process of solving the problem. Finally, the homework was disconnected from the way the rest of the course was taught. In-class work focused on understanding the process (setting the problem up correctly, etc.) but the online homework system focused on obtaining the correct numerical answer, regardless of how the problem was set up or what process a student used to solve the problem. Therefore, the instructor developed a structured problem-solving template that was used for in-class group work and homework. The goal of this paper is to explain the implementation of the structured homework system, present our comparison of student learning between the two homework systems (online homework system, structured homework system), discuss the student survey data, and present the design of a hybrid homework system currently being implemented.
Methods

Course Format: In Spring 2017 (online homework system) and Fall 2017 (structured homework system), the course was taught in a flipped format [17] in an active-learning classroom and utilized team-based learning [18]. Each class meeting consisted of: 1) individual and team readiness assurance tests (iRAT and tRAT using IClicker2), 2) team development, 3) lecture highlights, 4) example problem(s), and 5) group work. The instructional team consisted of the professor, two graduate teaching assistants (GTAs), and two undergraduate teaching fellows (UGTFs). UGTFs were undergraduates who had recently done well in the course and were embedded into the course to help with active-learning activities. The instructor, GTAs, and UGTFs walked around during the group work time to assist groups and/or individuals with questions.

Description of Homework Systems: In Fall 2017, the homework system changed compared to Spring 2017. The instructional team developed new homework problems, and a common homework template (example shown in Figure 6 at the end of the paper). The template included an instructor-provided problem statement and problem illustration. The student had specific places on the page to: a) gather information (givens and unknowns), b) organize their approach, c) sketch the system, d) analyze the problem symbolically, e) solve the problem with numbers, f) report final numerical answers, and g) reflect on the answer. Parts a, b, and c together were worth 2/10 points. Part d was worth 4/10 points, part e was worth 3.5/10 points, and part g was worth 0.5/10 points. To create the problems, GTAs browsed several dynamics books to understand the typical types of problems used, and then created problems similar in scope and content that addressed the learning objectives within each chapter. The homework solution template was designed to force students to utilize the problem-solving approach the instructor was working to develop. For instance, students had to draw a diagram of the system, which sometimes seems unnecessary to students early in the course because the problems are straightforward. However, forcing the student to develop the skill of utilizing a structured problem-solving method enables them to solve more complicated problems as the course progresses into harder material. Two structured homework problems were assigned for each class meeting.

The students were required to first solve the homework problems algebraically and determine the symbolic solution, before plugging in the given values and finding the numeric solution. This served several purposes: first, it helped the students think about the problem and the approach that they should take before they jump straight into plugging numbers into equations and seeing if they can come up with an answer. Secondly, this will allow for video solutions to be created that walk students through the solution to the problem but will only address the symbolic solution, as is done in the Purdue Freeform classroom [19]. By doing so, the same problems can be reused in future semesters, with new given parameters resulting in different answers for the problems, but the video solutions can remain the same because the problem-solving process remains the same.

One of the main advantages of the online homework system is that the students receive immediate feedback on their solution to the problem, which students appreciate and helps with learning the content. To deliver similar feedback with the new system, the students were given the numerical answers to each of the homework problems through the course website. By providing the numerical answer, the students could ensure that they were solving the problem correctly, and if they were not, then they could either try and fix their mistake or come to office hours to receive help on the problem. GradeScope was utilized for the students to turn in their solutions online and to provide rubric based and directed feedback on each section of their solutions before the next class session.
To help alleviate the amount of time required to develop additional homework problems that can be used in future semesters, student teams were given the opportunity to earn extra credit by developing one new problem for each learning objective within each chapter. They worked with their team to develop a complete and correct solution. In previous semesters, the students had been given an opportunity to solve extra problems through the online homework system and receive extra credit towards their semester grade. This gave the students a similar opportunity to boost their semester grade.

Learning Objectives: Three two-stage exams were given during each semester. Each exam consisted of four multiple choice questions. Each exam question was designed to assess the outcome of a learning objective, which were provided by the textbook (Hibbeler, 2016). Student performance on each question, for both stage one and two, were recorded and tracked for all three exams. The individual portion for each exam was used in this study (see Table 1 for the specific learning objectives that were compared across semesters). Although the specific problem testing each learning objective was not identical across the two semesters, they were of a similar level on Bloom’s Taxonomy [1]. Unfortunately, the number of comparable learning objectives were reduced due to a fire alarm taking place during the second exam of the Spring 2017 semester.

Table 1. Comparable learning objectives across semesters.

<table>
<thead>
<tr>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAPTER 12: Kinetics of a Particle</td>
</tr>
</tbody>
</table>
| 12.6   Projectile Motion  
LO 12.6 Analyze the free-flight motion of a projectile. |
| 12.9   Absolute Dependent Motion  
LO 12.9 Relate the positions, velocities, and accelerations of particles undergoing dependent motion. |
| CHAPTER 13: Kinetics of a Particle: Force and Acceleration |
| 13.4   EOM: Rectangular Coordinates  
LO 13.4 Apply Newton’s second law to determine forces and accelerations for particles in rectilinear motion. |
| 13.5   EOM: Normal & Tangential (n-t) Coordinates  
LO 13.5 Apply the equation of motion using normal and tangential coordinates. |
| CHAPTER 16: Planar Kinematics of a Rigid Body |
| 16.5   Relative-Motion Analysis: Velocity  
LO 16.5a Describe the velocity of a rigid body in terms of translation and rotation components.  
LO 16.5b Perform a relative-motion velocity analysis of a point on the body. |
| 16.7   Relative-Motion Analysis: Acceleration  
LO 16.7a Resolve the acceleration of a point on a body into components of translation and rotation.  
LO 16.7b Determine the acceleration of a point on a body by using a relative acceleration analysis. |
| CHAPTER 17: Planar Kinetics of a Rigid Body: Force and Acceleration |
| 17.1   Mass Moment of Inertia  
LO 17.1 Determine the mass moment of inertia of a rigid body or a system of rigid bodies. |
Concept Inventory: Our goal was to measure the impact of the change in the homework system used on student learning. Therefore, at the beginning and end of each semester, the students took the abbreviated Dynamics Concept Inventory [20], which is a research-based assessment instrument that measures conceptual understanding. Using the concept inventory data, we calculated the effect size, which is often used to compare pre- vs post concept inventory data to quantify student learning [21]. An effect size is an indicator of how substantially the pre- and post-test scores differ. The following values have been suggested for effect sizes: small (0.2), medium (0.5) and large (0.8).

Survey Description: A survey was sent via email to students who had taken the course in the previous semester (Spring 2017), and those that were currently in the course (Fall 2017) and using the new homework system. The survey asked Likert-scale questions about the following: “How often did you complete the homework assignments?” “How likely were you to have the solutions you generated available to you after turning in the homework?” and “How satisfied were you with the homework system?” Students were also asked, if given a new dynamics problem similar to what they have seen in the course, to rate their level of confidence in their ability to: 1) understand the problem and set it up correctly, 2) knowing the steps needed to solve the problem, and 3) getting the correct answer. Finally, students were asked for their open-ended responses to the following questions: “If you were given a dynamics problem similar to what you may have seen in the course, how would you go about solving it? Describe the process you would follow.” “What aspects of the homework system did you find effective in helping you to master the course content,” and “What aspects of the homework system did you find ineffective in helping you to master the course content?” Responses to the open-ended question about the process of solving the problem were reviewed and categorized as: “outlined the process in detail,” “outlined the basic process,” “vague or no outline of process,” and then those that indicated “googling it” or following a process “similar to the homework” were also noted.

Statistical Analysis: The Chi-squared test was used to compare the individual learning objective performance across the two semesters. The effect size was calculated using Cohen’s d, where: 
\[ d = \frac{<post> - <pre>}{stdev^*} \]

Results:

Three sources of data were analyzed to address the study objectives: learning objective performance, concept inventory pre- vs post-test scores, and student surveys.

Learning Objective Performance: Students in the semester with the structured homework system, compared to the online homework system, demonstrated statistically significant differences in performance on exam questions covering the same learning objective. A higher percentage of students in the structured homework system answered correctly on 3/7 learning objectives, and a lower percentage of students in the structured homework system answered correctly on 2/7 of the compared objectives (Figure 1).
Concept Inventory: Students in the structured homework semester showed a higher effect size on the pre-post concept inventory, indicating a more significant learning gain (medium compared to small effect) (Figure 2).

<table>
<thead>
<tr>
<th>Homework System</th>
<th>Effect Size(^1)</th>
<th>Effect Size Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured</td>
<td>0.47</td>
<td>Medium effect, important difference between pre- and post-test</td>
</tr>
<tr>
<td>Online</td>
<td>0.28</td>
<td>Small effect, unimportant difference between pre- and post-test</td>
</tr>
</tbody>
</table>

\(^1\)Estimated using Cohen’s $d = \frac{\text{<post> - <pre>}}{\text{stdev}}$, in which the stdev is the pooled standard deviation.

Survey Results: The survey was sent to 42 students who had taken the course in the Spring 2017 (online homework) semester, and 12 responses were collected. The survey was sent to 58 students who were enrolled in the Fall 2017 (structured homework) offering of the course, and 40 responses were collected. The comparisons made in this section are presented with the caveat that only 28% of the students who used the previous system responded to the survey.

Respondents in both offerings of the course reported completing the homework the majority of the time, but those using the structured homework system were more likely to “always” complete the assignment (80% compared to 58%). 78% of respondents using the structured homework system were either “extremely likely” or “somewhat likely” to have the solutions they generated available after turning in the homework, compared to 34% of respondents using the old system (Figure 3). This is consistent with what the instructor noticed, which is that after getting the correct answer to the homework on the online system, students often discarded their work. Of the respondents who utilized the online HW system, 50% were extremely or somewhat satisfied and 33.4% were extremely or somewhat dissatisfied.
For those who utilized the structured HW system, 80% were extremely or somewhat satisfied and 2.5% were extremely or somewhat dissatisfied (Figure 3).

<table>
<thead>
<tr>
<th>How likely were you to have the solutions you generated available to you after turning in HW?</th>
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<tbody>
<tr>
<td>% of Respondents</td>
</tr>
<tr>
<td>Extremely likely</td>
</tr>
<tr>
<td>Spring 2017 N=12 (Online Homework)</td>
</tr>
<tr>
<td>Fall 2017 N=40 (Structured Homework)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How satisfied were you with the homework system?</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Respondents</td>
</tr>
<tr>
<td>Extremely satisfied</td>
</tr>
<tr>
<td>Spring 2017 N=12 (Online Homework)</td>
</tr>
<tr>
<td>Fall 2017 N=40 (Structured Homework)</td>
</tr>
</tbody>
</table>

*Figure 3. Student survey results on likelihood to have solutions available and satisfaction with the homework system.*

When asked about their confidence level in setting up a problem, knowing the steps to solve, and getting the correct answer, respondents using the structured system were more confident than those who used the online system at “understanding the problem and setting it up correctly” and “knowing the steps need to solve the problem.” Students using the structured homework system were less confident than those who had used the old system at “getting the correct answer,” (Figure 4).
Responses to the open-ended question asking “If you were given a dynamics problem similar to what you may have seen in the course, how would you go about solving it? Describe the process you would follow,” were interesting. Two out of the ten from the online homework semester who answered the question responded that they would “google it.” None of the 32 responses from the structured homework system students referenced “googling it” or anything else related to looking for the answer online. Figure 5 shows the percentage of answers in each category for both semesters.

Figure 4. Student survey results on confidence in their problem-solving process

Figure 5. Student survey results on confidence in setting up and solving a similar type of problem
**Instructor Feedback:** The instructional team for the course reported being more highly satisfied with the engagement level of the class. In the Spring 2017 offering of the course (online homework system), the graduate teaching assistants reported seeing approximately 1 student per week in the 4 hours of office hours offered, and a total of 2-3 different students over the course of the semester. In the Fall 2017 offering of the course (structured homework system), the graduate teaching assistants reported seeing approximately 8-10 students in office hours each week, and a total of 15-20 different students over the course of the semester. Students seemed to understand the concepts associated with the course much better and came to office hours with the goal of understanding how to do the homework in the Fall 2017 class, instead of coming to office hours with the goal of getting the right answer on the homework, which was typically the case in the Spring 2017 course.

**Discussion**

The learning objective data based on comparable exam questions between semesters is not conclusive. A comparison of more learning objectives would be ideal, but unfortunately is not possible due to the fire alarm that happened during the second exam (making all of those learning objectives not comparable due to changes in the testing process to accommodate the fire alarm). The concept inventory data points to an improvement in learning gains in the semester that utilized the structured homework. There were no significant changes in the teaching pedagogy or topics covered between the two semesters—the major change was the homework system. The learning objective and concept inventory data provide insight into student learning and potential effects of the different homework systems, but they do not provide conclusive or causal outcomes. Perhaps the most convincing data comes from the students themselves and the impressions of the instructional team.

Feedback from students and the instructional team indicate that the structured homework was effective at getting students engaged with the homework earlier than normal, and at a deeper level than before—indicated by the much higher numbers of students spending time at office hours and the types of questions asked. Students in the semester that utilized the structured homework were more likely to keep their solutions and have them available to them for studying. They were also more than twice as likely to be able to describe, in detail, the process they would go through to solve a dynamics problem, compared to students utilizing the online system. Both of these outcomes address the motivation for creating the structured homework system.

The online homework system has many positive attributes, some of which have already been mentioned. For example, it is convenient to the instructor to set up the entire semester of homework, which is then automatically assigned, with availability and due dates. The system allows random numbers within the problem, it is automatically graded, and can be incorporated into the Learning Management System. Limited but immediate feedback is provided, multiple attempts can be allowed, hints are available, and adaptive learning is available. Even so, there are a few disadvantages. For example, the students tend to focus on the final answer, with little value placed on a structured solution. For our class, this represents a disconnect between the solution process focused on during in-class active learning. Students are not likely to retain a complete and organized solution to each problem. The students are required to pay an extra fee for access to the online homework system. Unfortunately, according to student feedback, the solution to the majority of the online problems are available online for free or from an online pay-to-do-your homework vendor.

The structured homework system used here has many positive attributes. The structured problem-solving template developed and required is used for all in-class example and group solving problems. The students scanned their structured solutions, submitted them to the online GradeScope system (free at the
time), and retained their original solution for later review. We used a common homework structure for all homework problems, with the solution spatially organized the same for all solutions. This allowed a common rubric for each region of the structured solution across all homework problems, giving the student and instructor feedback on each section of the solutions. The numerical answers were provided in advance for each problem, giving the student immediate feedback on the correctness of their solution and placing the focus on the solution. Since the problems were new, the solutions were not available online or in a solution manual (a point of contention by some of our students). The student teams were given the opportunity to earn extra credit for developing new problems that could be used in future semesters. Even so, there are a few disadvantages. Time and effort was required by the instruction team to create new homework problems and solutions. Directed feedback on homework performance was delayed by 1-2 days, although it was always available by the next class period. Grading the homework via GradeScope basically used up all of our allotted grader time (8-10 hrs/week). In the future, there may be a fee for the students to use GradeScope. Because both systems offer positive attributes along with some down sides, we have elected to develop a hybrid system.

**Hybrid Homework System**

Our team is currently implementing a hybrid approach, which takes advantage of the positive attributes of the online and structured systems. The online system is used to assign two end-of-section problems for each class session (typically covering 1-3 sections in the book). Multiple attempts are allowed, hints are available, late submission is allowed (a 2%/hr penalty), and adaptive learning is available for extra credit (those scoring 90% or above are given the adaptive learning extra credit). The student is required to write out structured solutions to each of the two required online problems and the structured solutions are occasionally collected for credit. Since this problem has already been graded via the online system, the structured solution is graded for completeness and the goal is to motivate the students to use structured solutions when preparing for the tests. Finally, for each chapter, two sets of extra credit problems are available when the chapter is first discussed in class and are due at the test time for that chapter. The first set includes many of the video and tutorial problems, giving the student access to valuable learning opportunities. The second set are fundamental problems for the chapter and serve as good practice problems when preparing for the tests. Our preliminary assessment of student survey results suggest that the hybrid approach retains many of the benefits provided by both the online and the structured systems.

**Conclusions**

Student learning should be used to influence the pedagogy used to teach a course. There are trade-offs when selecting either a structured or online homework system. Our study data supported our concerns regarding the negative impact of utilizing an online homework system, most of which can be corrected by utilizing a structured homework system. Unfortunately, educators often work in an environment of limited and/or diminished resources, making a structured homework system, as described in this study, difficult to implement. We believe that the hybrid homework system, as described in this study and currently being implemented, may represent a good compromise that takes advantage of the strengths of both the online and structured homework systems.
Acknowledgements

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References


HW Problem
Name: ___________________ Team #: ___ Student #: ___

LO: Find kinematic quantities (s, v, a) of a particle traveling along a straight path.

Problem Statement
An object has an initial position \( s_0 = 0 \ m \), and initial velocity \( v_0 \ [m/s] \), and is under an acceleration of \( a(t) = kt \ [m/s^2] \), \( t \) being in seconds, and \( k \) being a constant.

Determine:
1. The units of \( k \).
2. The equations describing the object’s velocity \( v(t) \) and position \( s(t) \) as a function of time.
3. The velocity in \([m/s]\) of the object when it has reached the position \( s = d \ [m] \).
4. The time in seconds that the object takes to reach \( s = d \ [m] \)

Remark:
- When solving questions 3 and 4, solve for the smallest positive time.

Problem Illustration.

A. Gather Information.
Given:

Find:

Parameter Values Provided:
\( v_0 = \)
\( k = \)
\( d = \)

B. Organize Your Approach.

Provide your strategy, principals and equations.

C. Sketch your system.

For example, provide the free body diagram (FBD) and kinetic diagram (KD), etc.

Figure 6. Structured homework template, page 1
D. Analyze the problem using symbols.
   Note: do not substitute in any numbers into your equations (e.g. initial conditions, parameter values, etc.). Must show all steps. Circle your final answers expressed in symbols.

Figure 6. Structured homework template page 2
LO: Find kinematic quantities (s, v, a) of a particle traveling along a straight path.

E. Crunch the numbers.
   Using results from step D, if provided, substitute in all numerical values for initial conditions, parameters, etc.

F. Report final numerical answers.
   1. 
   2. 
   3. 
   4. 

G. Reflection.
   Demonstrate that your numerical answers are reasonable.

Figure 6. Structured homework template page 3