

Teaching a Rigorous Problem-Solving Framework in Entry-Level Mechanical Engineering Courses – Theory and Practice

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Abstract

Although students in entry-level mechanical engineering courses have been through the Calculus and Physics sequence, they are often unprepared for the “new thinking” required to solve engineering analysis problems. The process of reading a description of a physical situation, deciding which analytical theory applies, converting the physical situation into a solvable mathematical model, and finally visualizing the forces and motions to evaluate the physical realism of the solution can be a daunting task. This paper studies the use of a problem-solving framework in a Dynamics class to help students to develop the skills needed for solving engineering mechanics problems. The framework initially serves as a “crutch” that helps students work their way from problem statement through solution, but ultimately it allows students to focus more on understanding key concepts because they are relieved of some pressure related to figuring out what to do next. Although assessment results from using a rigorous framework in the course have been generally positive, students are still reluctant to do what is perceived as “extra work” when they think they immediately know how to solve a problem and will abandon the framework in such cases if given the opportunity.

I. Introduction

When determining the most appropriate method of presenting material in an engineering course, many factors must be considered. Chief among these factors are the intellectual maturity level of the students and the desired objective or outcome of the course. Upper-level students should be given the freedom and responsibility of semi-autonomous learning, but entry-level engineering students often require a more structured format and more guidance both in what to learn and how to learn. Relative to course objectives, the major question is whether the emphasis should be on process or content. In other words, should successful students walk away from the course with an understanding of certain concepts and topics, or should they be skilled in applying a process for dealing with relatively generic problem situations. These issues have been considered extensively at Ohio University in relation to the entry-level engineering courses, and this paper reviews our attempts to increase student learning in a sophomore-level Dynamics course by increasing the emphasis on problem-solving frameworks.

II. Theory

The goal of increasing learning is a common one but is very abstract. In order to realize this goal it is necessary to identify student learning needs and current course deficiencies, implement concrete changes to a specific course or throughout the curriculum, monitor the effects of the changes, and reiterate the process for continuous improvement. The details of this process for a Dynamics course are given in the next section - this section focuses on one of the options for

teaching/presentation of course content, i.e. teaching Dynamics in the context of a problem-solving framework.

Historically, in the mechanical engineering curriculum Dynamics has been taught in a standard lecture/homework/exam format. Most of the material is presented conceptually then is reinforced by having students solve a relatively large number of “simplified” textbook problems, where simplified in this context refers to the fact that the problems are solved at a specific instant in time and the problem parameters are selected to allow for solution-by-hand (using calculators but not computers). Recently, as computers have become ubiquitous on college campuses instructors now have the option of focusing less on the algebraic manipulations for solving problems by hand and more on developing solvable mathematical models and using computational software for solution, simulation, and visualization. Regardless of the choice of emphasis, Dynamics is essentially a problem-solving course. It is desirable that Dynamics students master the process of reading a description of a physical situation, deciding which analytical theory applies, converting the physical situation into a solvable mathematical model, solving the mathematical model, and finally visualizing the forces and motions to evaluate the physical realism of the solution. Although some students can get through Dynamics without learning these problem-solving steps by modeling (or trying to solve new problems by copying the equations and methods used to solve similar problems), students are better prepared for the upper-level engineering curriculum if they develop good problem-solving habits in the entry-level courses. The basic idea is that a framework initially serves as a “crutch” that helps students work their way from problem statement through solution, but ultimately the framework allows students to focus more on understanding key concepts because they are relieved of some pressure related to figuring out what to do next.

Many scholars have researched and written about strategies (or frameworks) for problem solving. In fact, a recent Journal of Engineering Education article categorized more than 150 strategies that were either used or proposed for use in a number of different fields including science, mathematics, and engineering¹. Most of this research is from a strict problem solving perspective, seeking to develop the most useful set of steps or heuristics to help students or professionals in those fields to attack and solve problems efficiently and creatively. Assessments in several of those studies have shown that: 1) Students that received practice applying a strategy outperform, on numerous measures, students who did not receive such an experience¹, and 2) Upon reflection students appreciate the value added by the use of a strategy, making comments such as “I discovered that the same, organized approach can be applied to actively solve technical problems and to the problems of understanding new concepts and learning.”²

In an educational setting we are not only interested in helping students to develop practical skills for solving problems, we are also interested in the pedagogical effects of the use of a framework on student learning of concepts. Does the use of a framework help students to focus on understanding the underlying Dynamics concepts by greatly reducing their need to think about what to do next, or does the time spent on learning a specific problem-solving framework just take away from time that would be better spent discussing concepts or solving problems? These are difficult questions to answer explicitly, but at Ohio University we have taken steps to better understand these issues by trying various levels of intervention with respect to the use of

problem solving frameworks in a Dynamics course and assessing the outcomes. The remainder of this paper discusses these efforts.

III. Practice

Although students in entry-level mechanical engineering courses have been through the Calculus and Physics sequence, they are often unprepared for the “new thinking” required to solve engineering analysis problems. The process of reading a description of a physical situation, deciding which analytical theory applies, converting the physical situation into a solvable mathematical model, and finally visualizing the forces and motions to evaluate the physical realism of the solution can be a daunting task. To gauge student perceptions of their preparation for the Dynamics course and to evaluate the need for a problem-solving framework in the course, students in traditionally taught Dynamics courses were surveyed near the end of the course. Questions focused on how much various learning activities (in-class and outside class) and instructional materials contributed to learning in the course, and how much additional assistance the students thought they needed in various topics to better achieve the course learning objectives. Results from one class of 26 students, primarily Junior Mechanical Engineering students, show that students at this level believe the learning activities that contribute the most to their learning are lectures, the instructor solving problems for the class, and individual help during office hours and help sessions. Areas where students feel they need the most assistance are with overall problem-solving skills (88% report needing help) and evaluating results to determine if they are physically realistic (77% need help). Interestingly, only 38% of students report needing extra help with creating free body diagrams, although instructors have found this to be a problem area in upper-level engineering courses. Additional student comments indicate the desire for more worked problems and examples, and the strong feeling that any changes to the course should supplement rather than replace current course materials. A copy of this survey is available from the author upon request.

After reviewing student input from surveys and from other sources and instructor evaluations of student outcomes, we determined that current engineering mechanics teaching methods and materials are adequate but could likely be improved by supplements and a shift in emphasis. We believe effective educational materials must not only give students what they want (more worked examples so they can copy the exact same procedure in a homework problem or test), but also what they need (actual practice solving problems using good problem solving skills, requiring some synthesis rather than just ‘Xerox engineering’). It was with this background that we developed a general framework for solving dynamics problems. A copy of that original framework can be found in a previous paper.³ The framework was developed “by committee”, based on discussions between several faculty members that alternately teach the Dynamics course. It has been implemented in a standard classroom setting, as a guide for students to follow when doing homework problems and more extensive projects. In this case all assignments must follow the framework, and students must show their work for each of the applicable steps. Additionally, because of the continuing trend towards the use of technology for solving almost all engineering problems in industry, the framework was implemented in a web-based educational tool so that students can learn problem-solving skills in the mode that they will likely be using those skills, i.e. on a networked computer. In both cases the usability and usefulness of the framework were evaluated by student surveys. Since we are clearly in the

formative stage of evaluation for both the framework itself and the web-based educational tool, the evaluation results are generally positive but indicate numerous improvements that could be made to improve the framework's user friendliness.

Based upon student comments and our experience to date in using the framework in a Dynamics course, the original framework was simplified and clarified. The five main steps in the revised Dynamics problem solving framework are 1) Define problem, 2) Create diagrams, 3) Create mathematical model, 4) Solve mathematical model, 5) Check physical realism of result. Figure 1 parts A through E presents details of these 5 steps. This revised framework will initially be implemented off-line in a standard Dynamics course and will go through additional test cycles for evaluation, but eventually a final version of the framework will be implemented on-line in an updated version of the web-based Interactive Problem Solver. Further information on the web-based Interactive Problem Solver can be found in a separate paper in these proceedings.⁴

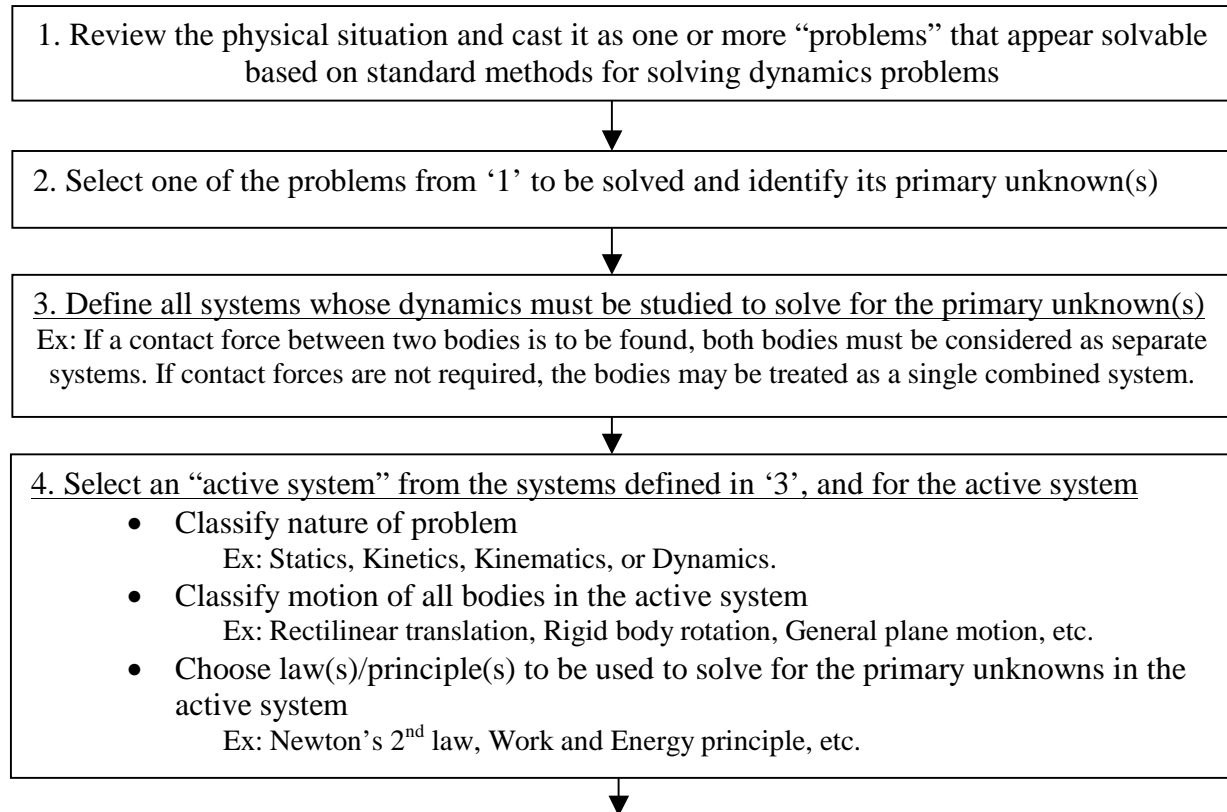
IV. Conclusions

As with all pedagogical experiments we have experienced some difficulties in implementing the course changes and the educational tools and evaluating their effects. There has been enough positive encouragement and success from our experience with using a framework in the Dynamics course to justify continued efforts to test the effectiveness of such frameworks in improving learning and problem-solving skills.

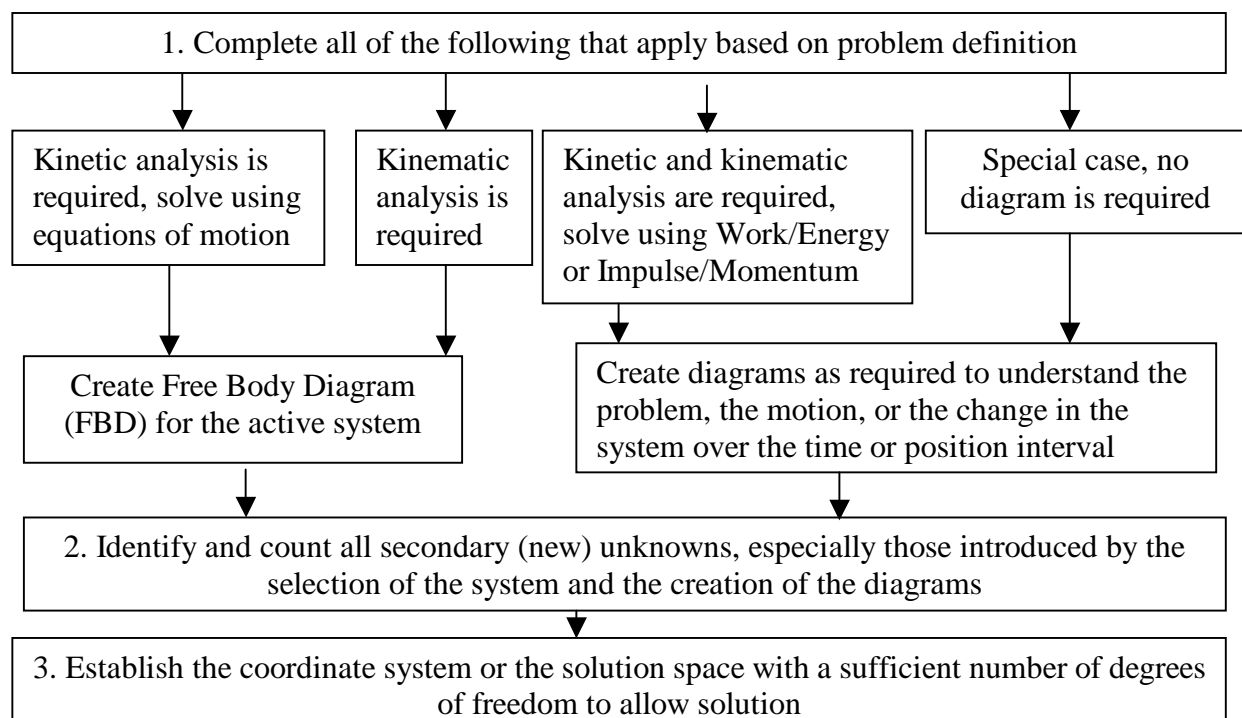
Although assessment results from using a rigorous framework in the course have been generally positive, students are still reluctant to do what is perceived as "extra work" when they think they immediately know how to solve a problem and will abandon the framework in such cases if given the opportunity. We are confident that revision two of the framework will be even more helpful and better accepted by students. In fact, we are investigating extending some of the same concepts throughout a "web-based curriculum" supplement.

Figure 1: General Framework for Solving Dynamics Problems

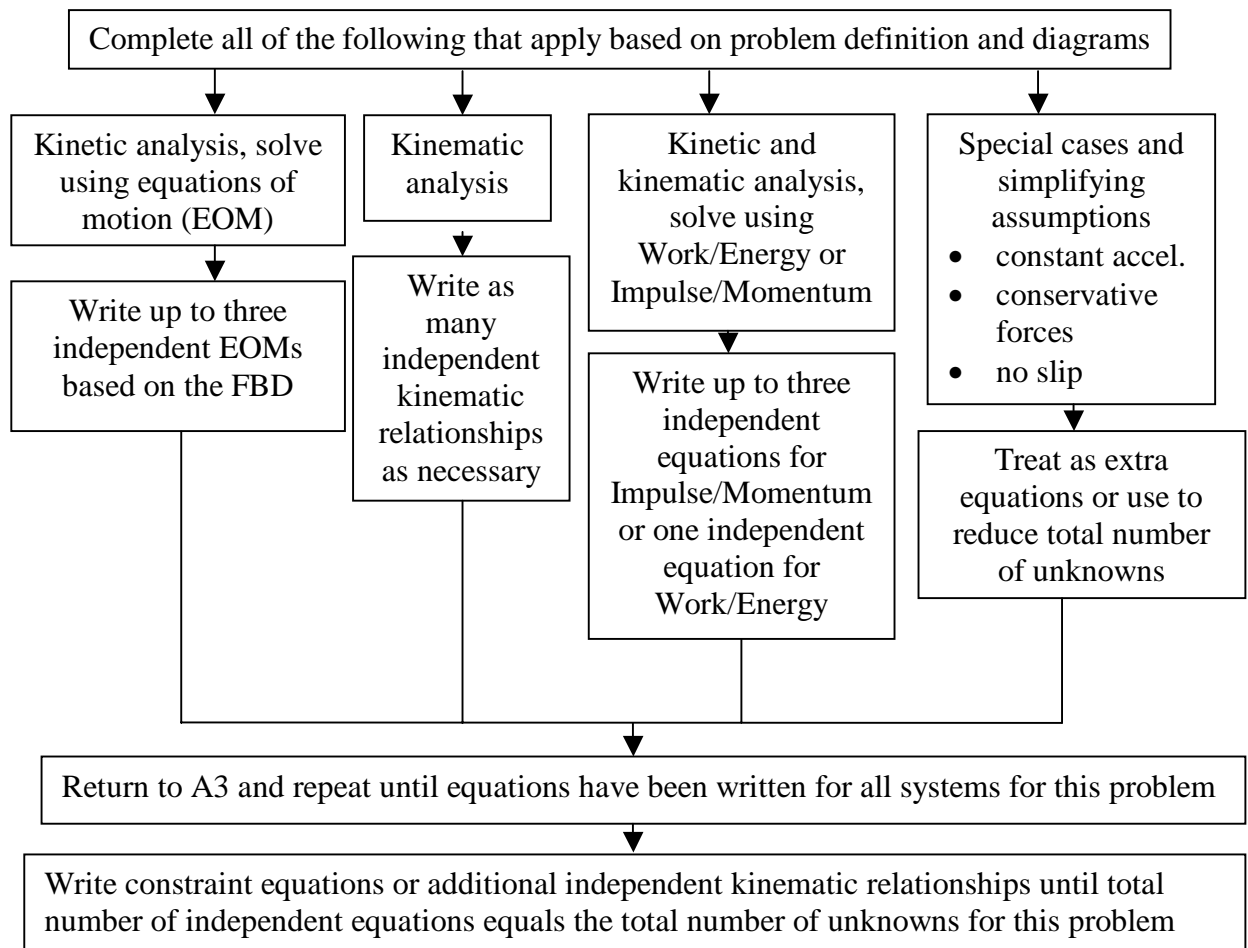
A) Define Problem



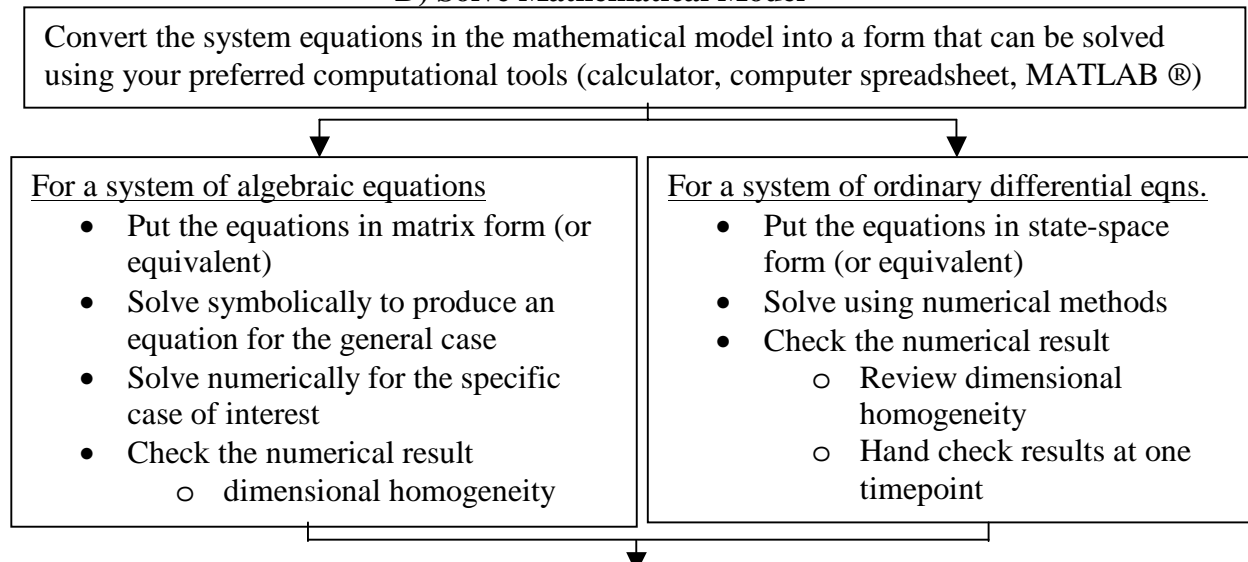
B) Create Diagrams



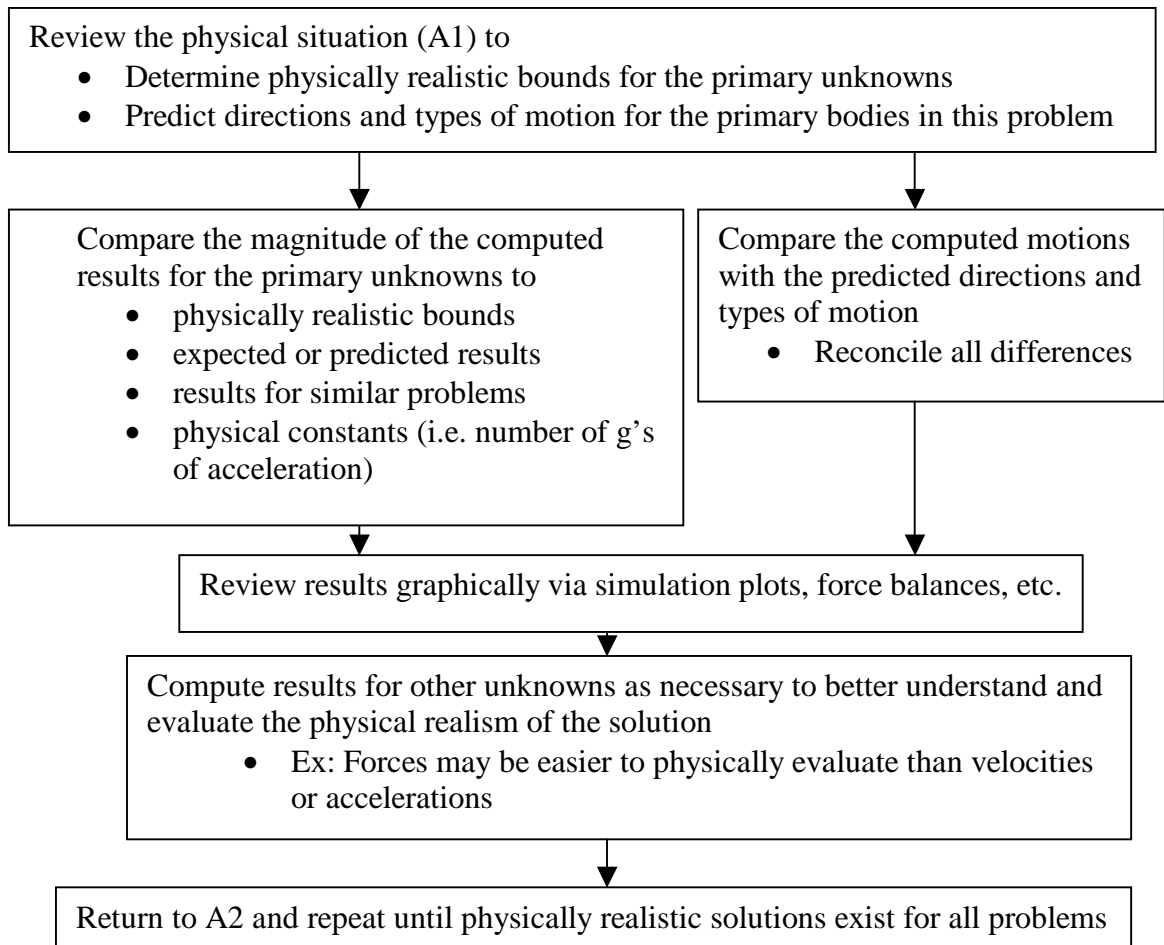
C) Create Mathematical Model



D) Solve Mathematical Model



E) Check Physical Realism of Result.



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