Improving Transitions Between Sophomore Dynamics and Junior Dynamic Systems Courses

Dr. Mark David Bedillion, South Dakota School of Mines and Technology

Dr. Mark Bedillion joined the Mechanical Engineering Department at the South Dakota School of Mines and Technology in January 2011 as an Associate Professor. Dr. Bedillion received the B.S. degree in 1998, the M.S. in 2001, and the Ph.D. degree in 2005, all from the Mechanical Engineering Department at Carnegie Mellon University. Prior to joining SDSM&T, Dr. Bedillion had an eight year career in the hard disk drive industry working on advanced data storage concepts. Dr. Bedillion’s research interests include distributed manipulation systems, robotics, control for data storage systems, control for advanced manufacturing systems, and STEM education.

Raymond Jon Raisanen, South Dakota School of Mines and Technology
Mr. Mohamed Hakeem Mohamed Nizar, SDSM&T Mechanical Engineering

I am an undergraduate student in mechanical engineering at South Dakota School of Mines & Technology. I am originally from Sri Lanka and I am here as a transfer student to complete my degree. My interests and goals are to work in design, manufacturing, or maintenance filed. Recently I have been working on SolidWorks motion analysis, and designing virtual models of dynamic systems using VRML and Simulink.
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Abstract

This paper describes two course modifications to sophomore dynamics to improve visualization skills and to improve knowledge transfer from sophomore to junior courses. The first course modification involves the use of SolidWorks motion simulations to visualize the motion of example problems taught throughout the course. The second course modification was the introduction of Lagrange’s equations of motion for conservative systems. An example problem is presented along with student feedback. Evaluation was performed using both the Dynamics Concept Inventory\textsuperscript{1} and student surveys.

Introduction

Students at the South Dakota School of Mines and Technology (SDSMT) consider both sophomore dynamics and junior dynamic systems courses “hard”, with both courses routinely having relatively high failure / dropout rates. The causes of this difficulty are diverse, but there appear to be some common issues.

• Basic physics skills are lacking. A pretest using the Dynamics Concept Inventory\textsuperscript{1} has shown students scoring near chance (27% exam scores vs. 20% chance) in sophomore dynamics. While some of the issues on the exam are to be expected, for instance on rigid body motion, the students have great difficulty with basic physics concepts such as Newton’s Third Law.

• Basic mathematics skills are lacking. Students seem to have fundamental difficulty with derivatives of both scalar and vector functions; such operations are intrinsic to the study of dynamics and dynamic systems.

• Visualization skills are lacking. This problem manifests in both sophomore dynamics and junior dynamic systems. Sophomore-level dynamics tends to cast problems of motion as snapshots rather than the continuous evolution of junior-level courses. This is primarily due to the mathematical maturity level of sophomore students; prerequisites include calculus and physics, but not differential equations. Thus most introductory dynamics texts (e.g. Hibbeler\textsuperscript{2}) do not introduce the concept of equations of motion, although there are some notable exceptions (e.g. Gray\textsuperscript{3}).
This paper describes two course modifications to sophomore dynamics to improve visualization skills and to improve knowledge transfer from sophomore to junior courses. It summarizes prior approaches by the authors while updating the examples and providing further evaluation of results. The first course modification involves the use of SolidWorks motion simulations to visualize the motion of example problems taught throughout the course. The examples are taken from Hibbeler; the work is similar to that of Fisher, but differs in that it uses SolidWorks rather than Adams for the simulation platform. The motion visualization confirms students’ intuition for simple problems and helps to develop it for interconnected rigid body motion. It also serves two other purposes: it provides software continuity in the curriculum (the introductory mechanical engineering course has a strong emphasis on SolidWorks at SDSMT) and prepares students for the continuous nature of junior dynamic systems. Due to poor participation limited evaluation was possible; strategies are presented for increasing student engagement in the process.

The second course modification was the introduction of Lagrange’s equations of motion for conservative systems. This formulation of dynamics is typically reserved for courses in which it can be derived, which students encounter in their senior years at the earliest. However, while difficult to derive, Lagrange’s equations are easy to use for conservative systems, even for sophomore students. They perform the functions of uniting energy methods with Newton’s second law and introduce students to the concept of equations of motion that will be used consistently in junior dynamic systems. An example project is presented along with student feedback.

SolidWorks for Visualization

Work integrating SolidWorks examples into the course can be broken into two categories: in-class examples and student assignments. In-class animations were used to discuss how assumptions made in calculations for instants in time change over the motion of an object. Student projects were used to engage students with the software so that they could simulate problems independently.

In-Class Examples

A full list of the in-class examples used can be found at http://webpages.sdsmt.edu/~mbedilli/Simulations2.html along with animations. This section will describe a subset of the examples; others are found in a prior paper by the authors. The SolidWorks examples used in class span from Newtonian mechanics of particles to rigid body impulse and momentum, covering chapters 13-19 in the class textbook.

A particle dynamics example is shown in Figs. 1 and 2. The ball is dropped from rest and impacts the wedge, which causes the wedge to move to the left while the ball bounces to the right. As the velocity plot in Fig. 2 shows, the ball continues to move downward after impacting the wedge; this is contrary to many students’ intuition. The authors believe that seeing the animation coupled with motion graphs helps students better understand the system’s evolution over time and the abrupt velocity changes caused by impacts.
Figure 1: Oblique impact example. The ball impacts the wedge, after which the wedge moves to the left while the ball bounces to the right.

Figure 2: Velocity plots for the example shown in Fig. 1. The plots show the instantaneous changes in velocity due to the impacts. The ball continues to bounce on the ground after impacting the wedge.
Figs. 3 and 4 show an example used to demonstrate the conservation of angular momentum for systems of rigid bodies. A bullet with known velocity is fired into a stationary rod, and the task is to predict the angular velocity of the rod immediately after the bullet embeds into the rod. Students are asked conceptually how important the caveat “immediately” is to the problem solution, with many correctly identifying the fact that gravity will generate a moment about the pin as the bar begins to rotate. The plot shown in Fig. 4 shows how quickly the assumption that angular momentum is conserved breaks down, with the calculated angular velocity changing by nearly 30% after only 200 ms. This is something that students can imagine, but the authors believe that seeing such an unambiguous plot is helpful in building students’ conceptual understanding.

**SolidWorks Assignments**

In addition to seeing examples in class, students were encouraged to develop SolidWorks simulation skills through use of a tutorial and four learning assignments. The addition of assignments was partially made in response to prior work in which student participation was lim-
Figure 4: Plot of angular velocity for the problem shown in Fig. 3. The plot confirms the analytical calculations, while also showing how quickly the conservation assumption breaks down after impact.

The tutorial, including assignments, may be found at http://webpages.sdsmt.edu/~mbedilli/Class%20Materials2.html. Assignments focused on the following topics:

- Students learn to apply forces to a body and include static and dynamic frictional contact between surfaces.
- Students learn how to apply linear springs and how to change stiffness, free length, and initial length.
- Students learn how to apply motors to perform kinematic studies.
- Students learn how to perform impact studies, with emphasis on solver settings and contact settings.

After a tutorial on each topic, students were asked to solve a set of problems related to that topic and using the same part models that were introduced in the lesson. Thus, the tutorial problems focus exclusively on aspects related to dynamics (mates between parts, contact conditions, etc.) rather than exercising students’ part modelling skills.

Results and Discussion

While everyone benefitted from seeing examples done in class using SolidWorks, only a subset of the class participated in the extra credit assignments. There were 24 students in the class, 4 of whom were Civil Engineering majors and 20 of whom were Mechanical Engineering majors. The Civil Engineering students were juniors and seniors, whereas the Mechanical Engineering students were predominantly sophomores. Course prerequisites include Calculus II, Statics, and Physics I. While it is not required, most students have completed or are concurrently enrolled in Calculus III. The students were given the possibility of earning up to 4% credit towards their final grade by completing all four SolidWorks assignments. Six students (25%) completed the
first assignment, three students (12.5%) completed the second and third assignments, and two students (8%) completed the fourth assignment. While there are likely many causes for the low participation, the authors believe that the following are most important:

- Four of the 24 students in the class were Civil Engineering majors, who had no prior experience using SolidWorks.
- The credit offered may have been insufficient to motivate students. Self-motivated students may complete this for their own benefits, but other students must feel that the extra credit is worth the effort. Of the three students that completed three assignments, one was a high performer, one a middle performer, and one a poor performer.

The Dynamics Concept Inventory\(^1\) was given as a pre- and post-test to assess the results of the intervention. However, given the extremely low participation rates, these data are not useful in evaluating the effectiveness of the SolidWorks assignments in improving student conceptual understanding. An exit survey of students found that the students who did the assignments found them useful, with four of five respondents rating them as "somewhat useful" and one respondent rating them as "very useful".

To rate the effectiveness increased student participation is necessary. Due to the course’s mixture of mechanical engineering and civil engineering students, mandatory participation for all students is not an option. However, in the next deployment assignments will be mandatory for mechanical engineering majors, with civil engineers given alternative assignments related to structural vibrations.

### Introducing Equations of Motion

The visualization exercises using SolidWorks are intended to help students see past the snapshot nature of sophomore dynamics. Introduction of the equations of motion is then used to create a mathematical framework for the study of this continuous motion, the same structure that will be used in the dynamics systems course. There are, however, several difficulties involved in introducing the equations of motion to (primarily) sophomores.

- The students do not have a background in differential equations. The mathematical prerequisite for the course is two semester of calculus, which means that the dynamics instructor must introduce the concept of differential equations for the equations of motion to make sense.
- Even if the students have been exposed to differential equations, the equations of motion do not typically have analytical solutions. The students have not been exposed to numerical solutions to ODEs, so it is difficult for them to connect the equations of motion to their intuition of system response.

The authors give a brief overview of what a differential equation is, setting this up by consistently emphasizing the derivative relationship between position, velocity, and acceleration throughout the class. They also provide graphs of solutions to in-class examples without teaching the mechanics
of the solutions. These graphs are then tied to the SolidWorks simulation results as shown in Figs. 2 and 4.

**Introducing Lagrange’s Equations**

In addition to these standard difficulties, the authors have added the challenge of teach partial derivatives by teaching the equations of motion via Lagrange’s equations. Lagrange’s equations, particularly for conservative mechanical systems, are relatively easy to implement for sophomore dynamics students. The equation has the form

\[
\frac{d}{dt} \frac{\partial T}{\partial \dot{q}_j} - \frac{\partial T}{\partial q_j} + \frac{\partial V}{\partial q_j} = 0,
\]

where \(T\) is the kinetic energy of the system, \(V\) is the potential energy of the system, and \(q_j\) is the \(j^{th}\) generalized coordinate. For the students this equation is pure magic; no attempt is made to derive or justify it.

One of the course’s main outcomes is for students to be able to calculate the kinetic and potential energies of particles and rigid bodies in planar motion. The reason that the authors have decided to introduce Lagrange’s equations is that they provide a bridge between energy-based methods and the Newton-Euler equations. The concept of generalized coordinates is glossed over, with the relevant coordinates given to students for each problem. Partial derivatives are quickly explained. Students seem to have little trouble with this concept; they tend to have much more difficulty with the chain rule, and want to treat all derivatives as partials.

**An Example Project**

This section describes a project given in Spring 2013; other example projects are given in a prior paper by the authors. The mechanical system is taken from Rao and shown in Fig. 5. This system combines a rigid body in the rolling disk with a particle in the trailer. Students are asked to derive the equations of motion in both Newtonian and Lagrangian frameworks. For this problem, the Lagrangian framework is substantially easier because it eliminates the unknown friction force between the trailer and the disk.

In addition to finding the equations of motion, students were asked to create a SolidWorks model of the system and simulate its motion. One student-generated model is shown in Fig. 6. Unfortunately, given that students cannot solve the equations of motion, the SolidWorks study is somewhat independent of the analytical results.

**Results and Discussion**

The main difficulty in teaching the equations of motion has been timing. They are not a required component of the curriculum, and so have lower priority than most other topics in the course. A project such as that shown in Fig. 5 requires students to calculate the kinetic energy of a rigid
Figure 5: Mechanical system to be modeled. The students find the equations of motion for the system using Newtonian and Lagrangian mechanics. The figure is from Rao.\textsuperscript{7}

Figure 6: A student model of the system of Fig. 5.

body, which is typically not taught until near the end of the course. In the past the authors have restricted the analysis to particles to mitigate this issue at the expense of completeness; a project with rigid bodies such as the one described herein provides a much more comprehensive course overview.

While it has been difficult to formally evaluate the effectiveness of this intervention, student response to these Lagrangian projects has been primarily positive. Some representative comments from students are below.

- “I feel that this type of project is useful for students and that you should continue with these types of projects in future semesters.”
- “I believe applying our dynamics knowledge to a model is a practical application as well as a good way to finish up the class.”
- “...it reinforced the fact that velocity, acceleration can be strictly viewed as time derivatives of displacement.”
- “Lagrangian method was impressive in that it can solve a dynamics problem with just pure math.”
- “I feel like I gain a much stronger understanding of the Newtonian method and a fairly good understanding of the Lagrangian method as well.”
- “Overall this was a very reasonable learning experience...”
Even though this problem has no obvious practical applications, the students felt that the project was more practical than the other work in the class. The authors believe that the students were commenting more the study of multiple interacting bodies than to the merits of this specific problem.

Conclusions and Future Work

This paper has discussed two course interventions in a sophomore-level dynamics course that are intended to improve student visualization and prepare students for their follow-on dynamic systems course. The use of SolidWorks allows students to use a familiar piece of software to improve visualization skills for planar motion. The introduction of the equations of motion helps students prepare to view dynamics as an application of differential equations, while the use of Lagrange’s equations unites energy methods with the Newton-Euler equations. The authors intend to continue use of both of these interventions in future semesters.

Evaluation of these interventions has proved to be difficult. One challenge has been poor student engagement with the SolidWorks assignments. Another, more fundamental difficulty is that the students are not tested on the intervention topics. Given that the interventions focus on a continuous view of motion, their impact is likely higher on dynamic systems outcomes than dynamics outcomes. Such changes would not be measureable via the Dynamics Concept Inventory,¹ nor should they necessarily improve exam outcomes in dynamics. Future work will focus on evaluation techniques that span between courses, taking into account the long intervention / measurement lag. The authors intend to develop a pre-test for dynamic systems that assesses both students’ knowledge of dynamics concepts and their ability to identify the equations of motion of simple mechanical systems.

References