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The Interactive Classroom and its Integration into the Mechanics Curriculum*

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A new project for the enhancement of undergraduate engineering courses via the use of computers in the classroom is being developed at Penn State University. This project involves the introduction of simulation and experiment in courses traditionally containing neither. The approach used in the renovation of this first course in Engineering Dynamics is described and compared to similar initiatives. A description of the strategy developed at Penn State is preceded by a brief history of the 'virtual classroom' concept, i.e., of an approach to education based on an intensive use of information technology.

INTRODUCTION

PREPARING STUDENTS to meet the expectations of both the job market and top university graduate programs is perhaps the principal objective of any undergraduate program. Achieving this goal requires a clear understanding of the current as well as future job and research markets. Accreditation boards such as ABET and agencies such as NSF play an important role in discerning these needs and therefore in offering a 'vision' that allows one to set the correct strategic goals. Many of the studies in engineering education have identified the lack of hands-on laboratory experience and the lack of integrated/interdisciplinary approaches as shortcomings of most of the current curricula [1–8]. In fact, the strategic goals set for engineering education institutions by ABET, stated in a recent report entitled 'ABET Criteria 2000' [2–5], include the following as standard skills to be mastered by students at the completion of their undergraduate degree:

- the ability of applying knowledge of mathematics, science and engineering;
- the ability to apply advanced mathematics in engineering problem solving;
- the ability to design and integrate contemporary analytical, computational and experimental practices;
- the ability to work in teams and to effectively communicate.

This complex set of skills cannot be provided by a few courses in an engineering curriculum. Ideally, the ability to work in teams and to use the computer as a platform supporting interdisciplinary integration and communication should be cultivated in students from the very beginning and throughout the undergraduate experience. It is therefore crucial that courses be developed integrating computation, data acquisition, data analysis, and information technology into the very process of learning. Professor J. M. Wilson, the current Dean of Undergraduate and Continuing Education at the Rensselaer Polytechnic Institute (RPI) in Troy (NY), states that colleges and universities should offer students a 'five Cs' approach to education [9]. That is, they should offer an integrated curriculum where contemporary engineering *content* is taught along with and through modern means of *communication*, in a *community* environment, in line with modern *cognition* theories and using *computers* as the modern-day pencils/slide rules/spreadsheets/drawing boards.

This paper presents one approach to addressing the problem of how to practically combine all the elements mentioned above into sophomore/junior level courses and, as an example, into the first Engineering Dynamics course. We will compare what we call the 'Virtual Classroom' concept that we are implementing in some our undergraduate dynamics sections with the 'traditional' undergraduate dynamics course at Penn State University. (The term 'interactive classroom' is used by educators at RPI to describe the environment in which they conduct their studio-based courses. We will used the term 'interactive classroom' to describe our efforts and to distinguish them from the efforts of others.)

THE 'VIRTUAL CLASSROOM': THEORY AND PRACTICE

This section describes some of the recent trends in undergraduate engineering education.

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In particular, a review of the effort initiated at RPI and its adaptation to the delivery of freshman/sophomore level physics instruction at Penn State is discussed. This discussion also touches on the extension of these methodologies to basic undergraduate engineering courses.

The RPI studio approach

About five years ago RPI began an aggressive process of undergraduate education reform. The outcome of this reform has been the restructuring of the entire undergraduate curriculum according to the so-called 'studio' concept [9–13]. The underlying philosophy of this approach is that the basic activities comprising instruction, that is, lecture, recitation and laboratory, are integrated into a single learning experience. Furthermore, the role played by instructors and students in the classroom is dramatically different with respect to more traditional teaching models. The teacher acts primarily as a 'listener' and as a mentor and/or advisor whereas the main active role of gathering the learning material and processing it is played by the students. In a studio course, students are organized in small teams, and their learning process is logistically supported by a so-called 'virtual classroom'. The latter is a space designed to host computer workstations arranged in such a way that students can perform a variety of activities including computer modeling and simulation, team discussions, team/instructor discussions, as well as participation in 'traditional' activities, such as observing the teacher addressing the entire class while writing on the board. The computer is an essential element of the virtual classroom. In fact, the computer is the tool used by students to analyze data pertaining to specific syllabus topics, to gather information from the World Wide Web (WWW) for discussion and utilization, to compile reports of their activity, and to perform simulations using the appropriate software.

From a pedagogical viewpoint, the objective of this type of instruction is the immersion of the student in an environment that is as close as possible to that of their future workplace, i.e., in a space modeled after the ABET guidelines presented in Section 1 [2–4]. This gives the student an environment in which computers are the central element of modeling, productivity, and communication and where engineers work in teams, making frequent use of their communication, management, and leadership skills.

The studio approach at RPI has been used to restructure undergraduate education in almost every field. Glinkowski *et al.* [14] have discussed the specifics of a studio-based dynamic systems course, whereas Maybe *et al.* [15] have formulated a studio approach to the teaching of circuits and electronics. Furthermore, Carlson *et al.* [16] have discussed the importance of motivating students in participating in this new educational methodology via a first year one credit-hour freshman seminar. Initial data collected at RPI [9, 14–16] confirm that students' performance as well as satisfaction have dramatically improved using the studio model, thus reinforcing the idea that these changes in undergraduate education are indeed a beneficial course on which to embark.

A careful and long-term assessment is necessary before declaring the studio course concept a complete success. Furthermore, it should be emphasized that the studio approach is not the only available strategy in the reform of undergraduate education and, in a national debate on such a broad and important subject, a healthy degree of diversity in pedagogical approaches should be considered a rather desirable fact. Regretfully, a complete review of the many efforts in the field of undergraduate education reform is outside the scope of this paper. However, the present authors wish to acknowledge some interesting initiatives that represent valid alternatives to the studio approach. For example, Freund *et al.* [17] have discussed a strategy implemented at Brown University (Providence, RI) where, after a substantial training in fundamental subjects such as mathematics and physics, a substantial design content is introduced in terminal courses in dynamics and mechanics of materials. The project on which the students are require to work incorporates the 'design, manufacture and use of actual industrial products, as opposed to using analogs of idealized textbook problems as models' (c.f. [17]).

Somewhat similar is the approach implemented at Northwestern University (Evanston, IL) and discussed by Brinson *et al.* [18]. Here the emphasis is on the integration of computational methods as well as design in basic mechanics courses so as to empower students to solve simple but realistic problems which would be essentially unsolvable using pencil and paper. The importance of high-level programming languages such as MATLAB or Mathematica is also discussed by Soutas-Little and Inman [19] as important tools for a concrete improvement of undergraduate mechanics courses. The initiatives at Brown and at Northwestern universities have been shown to be effective and rather popular among students [17, 18] and they are not isolated cases.

The present paper focuses on the development of variants of the studio approach and its application in the delivery of undergraduate dynamic courses. We will describe how the studio approach is being used at Penn State University and what elements of originality are being implemented.

The Penn State experience

In the Fall Semester 1996, the Physics Department at Penn State University began offering experimental sections of the first physics course in mechanics following an approach similar in spirit to that being undertaken at RPI. The present authors, being responsible for the development of course renovation for some related engineering courses, have been guests of the Physics Department and have directly observed their new instructional activities. This section contains a critical account of the authors' experience along with a description of their contribution to the expansion of curricular renovation.

The reformed undergraduate physics course in mechanics, which, at Penn State is called 'Dynamic Physics' to distinguish it from a corresponding RPI course, takes place in a classroom hosting roughly fifteen computers connected to a main server. The classroom is also equipped with educational devices, such as rollers, scales, force probes, motion sensors, calibratable catapults, and a video camera. These educational 'gadgets', all commercially available (*i.e.*, not specifically manufactured for or developed by the Penn State Physics Department), allow a team of students to design and perform simple, but highly illustrative experiments. Data collection, recording, and analysis take place in the classroom and are performed using computers.

Students are organized in teams of three individuals. Each team is assigned a computer and a corresponding workspace. Before coming to class, each individual student is required to have read and done homework on the portion of syllabus scheduled for that class period. At the beginning of each class period, students are briefed by the instructor on what task they need to perform that day and what physical concepts they will need to use or discuss. After the brief presentation, the students are given a 10–15 minute quiz, which is based upon the reading and homework they were scheduled to have done. If the students understood their reading and successfully completed the homework, the quiz should be easily completed. After the quiz, the various teams access the main server using a web browser to gather specific information concerning their scheduled activity.

The activity often consists of performing a simple experiment which is intended to illustrate a specific physical concept, such as the principle of conservation of linear momentum. Other times the physical concept to be examined is illustrated by a computer simulation using software such as Interactive Physics, which is capable of modeling the static and dynamic response of simple, two-dimensional physical systems consisting of particles and rigid bodies. (Interactive Physics is an easy-to-use modeling and simulation tool for mechanical systems. Models are created by drawing on-screen with a graphic interface and students can add objects like springs, dampers, ropes, and joints. In addition, students can measure attributes, such as velocity, acceleration, momentum, and energy, of the objects they create.)

Yet another type of activity might involve digitally analyzing the motion of a set of objects recorded in the form of a QuickTime movie. In other words, students may be required to study, say, the kinematic relations between position, velocity and acceleration by analyzing a movie depicting the motion of a given object. Again, this is done using software such as VideoPoint, which permits students to gather data concerning the position of an object in a sequence of frames relative to a user-selected co-ordinate system. (VideoPoint is produced by Lenox Softworks (Lenox, MA) and is a rather sophisticated, though inexpensive tool that allows one to acquire quantitative position versus time data from QuickTime movies by obtaining pixel positions on the movie and then calibrating them with an object of known length on the movie.)

When an activity is carried out, the various teams are required to compile a written report, using appropriate software, which is resident on their computers. Since not all of the information required to carry out an activity is always resident on the various computers or on the server, the students are sometimes required to scour the Internet in search of what they need.

The main difference between Dynamic Physics and Studio Physics at RPI is the choice of software available to students. Initially, the RPI developments required the development of all new software, which was specifically designed to carry out a well-defined educational activity. The software used in the Dynamics Physics classroom is off-the-shelf, commercially available software. Although seemingly subtle, this difference has some potentially important pedagogical ramifications. In fact, the use of software not specifically designed for classroom activity forces the students to rely on their imagination and spirit of improvisation to find ways to adapt given tools to their required work. This choice therefore reinforces the idea of placing students in as similar an environment to the real work place as possible, where 'old tools' will have to be used to perform 'new tasks' before new tools can be developed.

Another difference regards the overall structure of the undergraduate curriculum. Whereas at RPI the first physics course in mechanics has been combined with the first engineering course in dynamics, at Penn State the two courses have been kept separate, but are becoming co-ordinated. This co-ordination will take on two forms. First, the Dynamic Physics content will be streamlined with that of the corresponding Engineering Dynamics course. Second, elements of engineering problems will be introduced early in the curriculum, beginning with the physics courses. This will allow instructors to avoid repetition and to modify the content of the Engineering Dynamics courses to more completely cover topics already covered, to cover more advanced topics, and to stress the engineering aspect of the course with the possible introduction of simple design problems.

Dynamic physics and further development in engineering

The idea of delivering and enhancing instruction using the same technology employed in the workplace is perhaps the most appealing aspect of the idea of the Interactive Classroom. However, this capability is largely dependent on having all the necessary equipment working properly. When a computer does not work because of some obscure bug in a Java applet or because of a weakness in the operating system, it is not uncommon to spend hours trying to get the systems working properly again. The occurrence of these problems during a class period is disastrous. Hence, one of the practical essential elements of the Interactive Classroom is the presence of a (computer) systems manager, that is, an expert in the computer systems being utilized in class and whose task is to ensure the absence of malfunctions during class time. The systems manager should also be responsible for maintaining and upgrading both hardware and software. This observation is essential to the understanding that designing a successful Interactive Classroom entails not only expenses for the acquisition of the necessary hardware and software, but also an ongoing expense of proper maintenance of the classroom. This also implies that the widespread success of the Interactive Classroom as an educational approach relies heavily on assessing whether or not the benefits of this new type of instruction offset the increased expenditures, and, possibly, justifies higher tuition fees.

Another appealing aspect of the Interactive Classroom approach is that of making the students the *active* element of the instructional process. This idea is similar to the ancient Socratic method in which the student is also the teacher and the instructor plays a role similar to that of a 'midwife' who is merely facilitating the learning process. Appealing as it is, this process is potentially time consuming for the instructor, time few instructors are able or willing to afford. In fact, different student teams may proceed through the learning process at significantly different rates creating situations where boredom or anxiety are present. Furthermore, especially in performing experiments, students need to learn how to make sure that all measurements are meaningful, how to filter out spurious or polluted data and, most importantly, how to account for the differences and similarities between the data collected and the theoretical concepts that they are trying to explore. In other words, it would be rather disappointing to see a student become skeptical about the principle of conservation of energy for the simple fact that, in a simple experiment conducted with simple tools, the true total energy involved could not be measured. Furthermore, students' confidence may be hurt if, regardless of how hard they tried, their experimental results are always significantly far from the theoretical prediction. Clearly, these same disappointments *do* have an enormous educational value. It is essential that the students learn about how difficult it is to carry out accurate experiments and how to go about formulating a correct abstraction process while formulating a theory.

The Interactive Classroom is only as effective as the management provided by the instructor. Therefore, the role reversal mentioned earlier where the student is the actual active instructional element is not entirely correct. A better model is perhaps one where the student is considered the *potentially active* learning element, provided the instructing faculty have done sufficient class management (behind the scenes, so to speak) to allow students to become active learners. At the same time the class preparation should not be excessive, so that the students are not given the feeling of going through a 'canned' learning experience.

The present authors have spent a semester assembling the coursework for the sophomore level Engineering Dynamics course at Penn State. In a first attempt to put the above considerations into practice, the class material has been managed using an approach consisting of two steps. For every planned activity in the Interactive Classroom, two sub-activities will be carried out. The first one will be a simple activity where experimental difficulties are completely avoided or kept to a minimum. This first activity is therefore designed to reinforce rather than test the theoretical concept to be examined during a given class period. The second activity will be one with open-ended questions where the students will have to deal with actual experiments and the complexities associated with experimentation. Furthermore, in order to stress the difference between the Engineering Dynamics and the Dynamic Physics courses, the former will focus more on simulation rather than on verification of physical concepts. In other words, the focus of the engineering course will be the modeling of motion so as to achieve a desired result, which is then experimentally tested after a theoretical prediction is formed. This approach should reinforce the approach to engineering design where the project's specifications are followed by modeling and prototyping.

Other issues concerning the successful realization of the Interactive Classroom approach regard the management of the various student teams in the classroom. An in-depth discussion of team instruction is outside the scope of the current paper, however, the present authors feel that the theory and practice of team instruction is a fundamental building block of the Interactive Classroom approach. For this reason, the reform of undergraduate courses in the College of Engineering at Penn State is being designed in co-operation with experts on team-based education and will be subject to a careful scrutiny. The results of our interaction with these experts and of our implementation of teams will be the subject of a future publication.

INTERACTIVE DYNAMICS VS. TRADITIONAL DYNAMICS

Even though we have touched on some aspects of a comparison between Interactive Dynamics and a traditional dynamics course, we now present a more comprehensive comparison of the two approaches, discuss the advantages and disadvantages of each, and discuss why we feel the students learn better and learn more using the Interactive Dynamics approach.

The traditional dynamics course

We are all familiar with traditional 'chalk-and-talk' mode of teaching undergraduates. In this mode, an instructor shows up three times a week to give a one hour lecture in which, if the students are lucky, the instructor will have 5–10 minutes of interaction with them in the form of questions and answers. During this one hour lecture, the students will take notes on theory and on example problems presented by the instructor. The class is usually structured so that the students are required to do homework problems out of the text (sometimes they are collected for credit) and two or three times per semester, the students are required to take a mid-term exam. In the typical dynamics course structured in this manner, there is little or no use or implementation of:

- computers in or out of the classroom;
- students working in teams or interacting with one another in any manner;
- required writing assignments;
- students presenting their work to their peers;
- hands-on or laboratory experience.

On the other hand, students are placed in an environment about which they are very familiar and in which they are very comfortable. The instructor is also teaching in an environment in which he or she is very comfortable and this contributes to the students feeling more at ease. In fact, the instructor is really at liberty to use the same set of notes every semester without any need to change those notes from semester to semester.

The Introductory Dynamics course

As with a traditional dynamics class, the typical Interactive Dynamics class assigns homework problems (as with traditional dynamics, these may or may not be graded), has two or three mid-term exams per semester, and even uses traditional dynamics-type lectures 30–40% of the time. It is the other 60–70% of the class that profoundly distinguishes Interactive Dynamics from traditional dynamics and we will refer to one of those distinguishing class periods as an Interactive Dynamics class. As has been alluded to in preceding sections, an Interactive Dynamics class typically begins with a 10–20 minute introductory lecture in which we present the goal of the day's activity and point out any particularly important things the students should look for during the activity. After the introductory lecture, the activity begins.

We do not 'take the students by the hand' as they work their way through each activity. Each activity is presented to the students as a project which they have a given amount of time to complete and for which they have a certain set of tools (e.g., Excel, VideoPoint, MATLAB, Mathematica, the Internet, rulers, scales, etc.). In fact, we try to make the process of completing each activity to be as real-world as we can make it. In this sense, the students are the active element in their education and the instructor plays the role of listener, mentor, and advisor. (Software tools were chosen based on our knowledge of and experience with these tools and on feedback obtained from industrial liaisons with our college.)

Within each activity, we de-emphasize the notion, almost universally espoused in undergraduate dynamics, that we only want 'the acceleration when $\theta = 30^\circ$. We do emphasize the notion that dynamics is about equations of motion and finding loads on systems for the purpose of design. In addition, each activity requires the students to work in teams and to either take on or assign roles for each of the team members. This requires communication, leadership, and management skills that are typically not required of students in the first dynamics course. Finally, Interactive Dynamics introduces its students to an abundance of concepts and ideas that students in a traditional dynamics course never see. For example:

- Even though a course in ordinary differential equations is not a pre-requisite for undergraduate dynamics at Penn State, the students are given a thorough introduction to the language of ordinary differential equations (e.g., dependent vs. independent variables, order of the equation, linearity vs. nonlinearity, coupled vs. uncoupled, initial conditions) and some simple numerical methods (e.g., Euler's method, second-order Runge-Kutta) for solving them.
- The utility and problems associated with numerical derivatives are presented and used. In all cases where numerical analysis is used, idea of different types of numerical error are introduced and discussed.
- Students are introduced to trajectories of differential equations and how different types of plots can be used to study their behavior.
- Students are introduced to the concept of equilibrium and steady-state solutions, ways of finding them, and ways to interpret them.
- With every activity, correct technical report writing skills are emphasized.
- The scientific method and the science and art of engineering are discussed and emphasized as often as possible. Students are frequently asked to postulate how something might work based on their learning and experience and then are encouraged to discover that they have the means by which they can prove or disprove their postulate. They are expected to compare predicted quantities with measured quantities, and

they are expected to comment on possible sources of error.

All of these things make the Interactive Dynamics classroom a place that is much closer to the work environment that the students will experience when they leave school and also better prepares students for many of the classes they will take in the remainder of their undergraduate career.

Remarks on the Interactive Classroom lecture

At the end of the activity, in addition to assigned homework, each team is required to submit a short report on that day's activity. This poses the problem of how to quantify the effort of each individual member of the team. Following strategies for the management of team-based learning [20–23], the grade that an individual is given is determined not only by the team report, but also by other factors. The latter include the overall performance of an individual in exams and quizzes, as well as peer assessment. This helps us deal with a common problem when teams are used in classes—the situation in which a team member or team members either do not or are perceived to not be 'carrying their weight'. As far as the written report is concerned, this is expected to be a well-formatted document, typed using a word-processor, written in clear English, complete with typeset equations and figures where appropriate. Part of the report grade is reserved for propriety in language.

We must emphasize that even though the activities are an integral part of the course, are a vital learning tool, and count for a significant portion of their final grade (approximately 45%), they do not take place every class period. In fact, approximately 10–12 of the 30 periods during the semester are used for activities such as those described above.

To give a picture of the make-up of an activity, we now present a pair of detailed examples of activities we have used in Interactive Dynamics.

THE STRUCTURE OF AN ACTIVITY

We now present a pair of typical Interactive Classroom activities that have been used in Interactive Dynamics through the description of what occurs during a typical lecture. Within these examples, we will describe in some detail all of the activity of an entire two-hour class period and what each activity is trying to address pedagogically. (The undergraduate Interactive Dynamics course at Penn State is a three credit-hour course, but the interactive classroom sections meet four hours per week due to the 'laboratory' component.)

A class period containing an Interactive Classroom activity will typically begin with a 15–30 minute introductory lecture in which we present the goal of the day's activity and point out any particularly important things the students should look for. After the introductory lecture, the activity begins.

Activity 1: Numerical solution of equations of motion

The first activity emphasizes a point that is not often made in the first course in dynamics, namely that dynamics is about equations of motion and motion over an interval of time and not about motion at a specific instant in time. This activity is purely analytical in nature and shows the students that within the first three or four weeks of the course they have the ability to derive equations of motion describing complex systems and that, with a little effort, they have the ability to numerically solve these equations to make predictions about the motion.

We begin class be doing an example problem whose solution requires the derivation and solution of an equation of motion. We convince the students that the equation we have derived is not solvable analytically and that we must resort to some other means. This provides for a transition to the numerical solution of differential equations of motion and Euler's method. We then proceed to spend approximately 40 minutes presenting Euler's method and Heun's method, which is a modified, more accurate version of Euler's method. After this is done, the instructor, as well as every team in the class opens their web browser to see the activity.

The activity is presented entirely via the web within a browser. It begins with a short introduction to scientific computing with some interesting links to other web sites (in this activity, this includes links to sites such as *The Computer Museum* at http://www.tcm.org/ and the *NIST Guide to Available Mathematical Software* at http://gams.nist.gov/). It continues by paralleling our lecture, that is, by helping students understand what 'equations of motion' are and helping them see that most equations of motion cannot be solved analytically. The activity then points out that all is not lost and that there are myriads of ways of approximating the solutions to these equations.

We then present two problems to them:

1. A two degrees-of-freedom elastic pendulum.
2. A two degrees-of-freedom system consisting of a mass on one end of an elastic rod the other end of which is pinned. The system slides in the horizontal plane on a viscous layer and is undergoing a constant torque at the pinned end.

An elastic pendulum. For this part of the activity, the students are given the appropriate physical parameters of the system in the following statement (also see Fig. 1):

> The 0.25-kg mass, which is attached to the elastic rod of stiffness 10 N/m and undeformed length 0.5 m, is

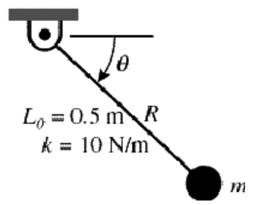

Fig. 1. Diagram illustrating the elastic pendulum described in the activity.

free to move in the vertical plane under the influence of gravity. The mass is released from rest when the angle $\theta = 0°$ with the rod stretched 0.25 m. Assume that the rod can only undergo tension and compression and that it always remains straight as the pendulum swings in the vertical plane.

We then ask the students to:

1. Derive the equations of motion for this system and state the initial conditions.
2. Solve the equations numerically from the time of release ($t = 0$) until $t = 10$ s.
3. Find the maximum speed of the mass during this period of integration.
4. Determine the maximum value of R and the first value of θ when the rod becomes slack.
5. Plot R and θ versus θ.
6. Plot the actual trajectory of the mass as you would see it for $t = 0$ until $t = 10$ s.

Parts 2–6 of this activity are all performed in Microsoft Excel.

A whirling mass in a horizontal plane. As part of the same activity in which the students analyze the elastic pendulum, we also ask them to analyze a two degrees-of-freedom problem described in the following statement:

> With reference to Fig. 2, consider a mass of 0.25 kg sliding on the horizontal surface forming the xy-plane. The surface is covered by a film of lubricant intended to facilitate the sliding motion, but which also provides a viscous resistance to the motion. The action of the lubricant on the moving mass is equivalent to a viscous resistance force, which is proportional to the velocity of the mass and has a viscosity coefficient $c = 0.3\,\text{N} \cdot \text{s/m}$. The mass is connected to the (fixed) origin of the xy-plane via an elastic rod which has a free length $L = 0.5$ m and elasticity constant $k = 100$ N/m. The rod can elastically extend but cannot bend. The mass is acted upon by a force $F = 5.0/R$ N oriented always in a direction perpendicular to the rod, where R is the length of the rod. From a physical viewpoint, the force F results from the application of a constant moment of magnitude 5.0 N·m applied to the elastic rod. At time $t = 0$, the mass is at rest with an initial position characterized by $R = 0.1$ m and $y = 0$.

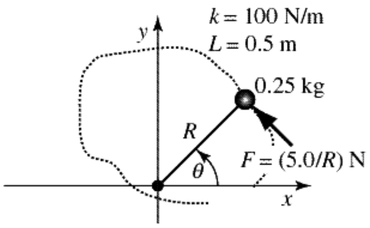

Fig. 2. Material point sliding on the xy-plane while attached at the end of an elastic rod.

We then ask the students to perform the following tasks:

1. Derive the equations of motion and state the corresponding initial conditions.
2. You will discover that after some time this system will be characterized by a circular motion with constant angular velocity. For convenience (and because this is how engineers refer to it), this part of the motion will be referred to as the steady-state solution. Analytically (i.e., non-numerically) determine the radius of the circular trajectory and the corresponding value of the angular velocity for the steady state solution.
3. Numerically integrate the equations of motion to compute and then plot the trajectory of the mass during the interval of time $0 < t < 5$ s. Verify that the trajectory will, at some point, coincide with the circle determined in item 2.
4. Finally, repeat the operations done in item 3 for other two sets of arbitrarily assigned initial conditions and verify that, regardless of initial conditions the motion of the mass will converge to the steady-state solution. Provide a physical explanation for this behavior.

Benefits of Activity 1. This activity reinforces and gives the students practice in the application of Newton's second law in polar co-ordinates and demonstrates the equation of motion nature of dynamics. In addition, even though a course in ordinary differential equations is not a prerequisite for undergraduate dynamics at Penn State, the students are given a thorough introduction to the language of ordinary differential equations (e.g., dependent vs. independent variables, order of the equation, linearity vs. nonlinearity, coupled vs. uncoupled, initial conditions). Finally, the students are exposed to topics that are not typically covered in an undergraduate dynamics course:

- numerical analysis and the idea of different types of numerical error;
- trajectories of differential equations and how different types of plots can be used to study and visualize their behavior;
- steady-state solutions, ways of finding them, and their physical interpretation;
- as with every activity, correct technical report writing skills are emphasized.

Activity 2: Experiment and prediction in particle impact

Later in the course (the 6th or 7th week of a 15-week semester) we do an activity on particle impact. The activity consists of two parts. In the first part of the activity, the goal is to be able to predict the rebound height of the top ball in a stack of three balls. In the second part, the goal is to analyze a ballistic pendulum to approximate the entrance velocity of a .22 caliber bullet and then to estimate the percentage of energy lost during the impact.

We begin the activity with a very short introduction (approximately 10 minutes) to the impact problems we will be considering and a demonstration of the impact phenomenon that occurs when multiple balls are dropped in a vertical stack.

Impact experiment and prediction for a stack of balls. In this part of the activity, the students discover through experiment and prediction an impact/rebound phenomenon that occurs when multiple balls are stacked and then dropped. We begin by asking the students to perform an impact calculation for a highly idealized case, that is, when n balls are stacked on top of one another and then dropped from a height h_0 (see Fig. 3 for the first three balls in the stack).

We ask them to begin by assuming that they have stacked just two balls, m_1 and m_2, that m_2 is on top of m_1, that the mass of $m_2 \ll m_1$ (i.e., $m_2/m_1 \approx 0$), that all impacts are perfectly elastic ($e = 1$), and that they are both dropped from a height h_0. We then ask them to compute the rebound height of mass m_2 as a function of h_0. They discover, sometimes with a little help from us, that the rebound height h_2 of mass m_2 is $9h_0$. We then ask them to do the calculation for three ($h_3 = 49h_0$), then four balls ($h_4 = 225h_0$) and to infer a general relationship for n balls (it turns out that $h_n = (2^n - 1)^2 h_0$). This calculation gives the students a feel for how to do the direct central impact calculations and also puts an upper-bound on the non-ideal case they are about to work with.

We then tell the students that they are now going to use some real balls to do this calculation and that they will actually do the experiment with three balls to see how their predicted rebound height will compare with the one they will measure. They begin by picking three balls they are going to stack (we provide them with basketballs, rubber 'superballs' and the like) and measuring the appropriate coefficients of restitution. An important aspect of this activity is their discovery of not only how they might measure e for various impacts, but also how e depends on many different factors such as the materials involved and the impact velocity. Having measured all the appropriate coefficients of restitution, they then measure the mass of each ball using a scale provided. Having made all of these measurements, the students then must *predict* what the rebound height of the third ball in the three ball stack is going to be when dropped from a known height. Finally, having made this prediction, the students actually do the experiment for which they have just predicted the result. As part of their activity report, they are asked to explain the differences they see between their predicted and measured rebound heights.

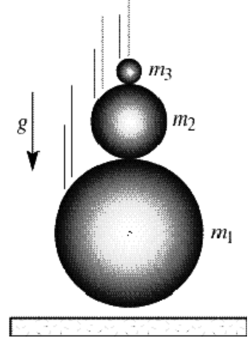

Fig. 3. Diagram of the stacked balls used in the particle impact activity.

The ballistic pendulum. The second part of the particle impact activity is the analysis of a ballistic pendulum (see Fig. 4).

To get the raw data for their analysis, the students use VideoPoint video analysis software to get the position swing angle of a ballistic pendulum from a QuickTime movie we created at a firing range. After approximating the angle from their data, the students are expected to use impulse-momentum relationships and work-energy principles to ascertain the impact velocity of the bullet with the wooden block. They are asked to compare their computed velocity with the velocity measured with an electronic device used at the firing range. In addition, we ask the students to compute the percentage of energy lost during the plastic impact, thus demonstrating that not only is mechanical energy not conserved, but that more than 99% of the original energy of the bullet is lost during the impact.

Benefits of Activity 2. Both parts of this activity reinforce the concepts of particle impact through analysis and experiment. In particular:

- The students see the origin of the coefficient of restitution and its dependence on material properties and impact velocity.
- In both parts of the activity, they are expected to compare predicted quantities with measured quantities and in both parts, they are expected to comment on possible sources of error. As part

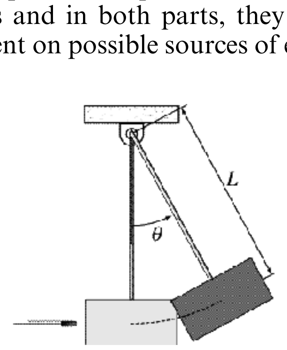

Fig. 4. Diagram of the ballistic pendulum used in the particle impact activity. The pendulum consists of a wooden block at the end of a slender wooden dowel.

of this, the ballistic pendulum part of the activity reinforces the validity of the scientific process since the electronically measured value of the bullet velocity is usually within 5% of the value the students derive from the QuickTime movie.

- They see a dramatic demonstration of the loss of energy in plastic impacts.

TOOLS FOR ASSESSMENT

Assessment of the success or failure of our new Interactive Dynamics course depends on how we define success and failure. For us, success entails a large number of criteria, some of which one would associate with a typical undergraduate course in dynamics and some of which one would not. In particular, we are using outcomes-based assessment to measure student performance in the following areas:

- conceptual and quantitative understanding of fundamental and important topics in undergraduate dynamics, including the ability to solve problems in these areas;
- ability to write a good technical report;
- proficiency with modern computer tools such as spreadsheets and web browsers;
- academic topics not usually associated with dynamics courses such as knowledge of numerical analysis, data analysis, and error analysis.

Part of this assessment is being carried out using a 'standardized' dynamics pre- and post-test program containing both quantitative and conceptual questions [24]. This test is being administered at the beginning and end of each semester to both traditional and Interactive Dynamics sections of undergraduate dynamics. The authors also have the co-operation of most other dynamics faculty and are administering common exams (midterms and final) in all of those classes. Consequently, we will be able to compare the performance throughout the semester of students in Interactive Dynamics sections with those students taking traditional sections of dynamics. These measures will tell us whether or not Interactive Dynamics is promoting a better understanding of dynamics, but they will not indicate whether or not students are benefiting from the non-dynamics aspects of the course [25]. In order to assess the success of these non-dynamics aspects, we are going to track students throughout the remainder of their academic careers to measure their performance in courses that depend on writing skills (e.g., technical writing and/or courses designated as having an intensive writing component) and computer skills (e.g., numerical analysis).

SUMMARY

This paper describes a project for the restructuring of a sophomore-level course in dynamics so as to closely conform to the guidelines of ABET 2000. This includes the use of computers in the classroom, cooperative or team learning, the use of good technical writing skills, and a pervasive use of ideas of the art and science of engineering in formulating and solving problems. We have called this approach to engineering education the Interactive Classroom and when applied to undergraduate dynamics, Interactive Dynamics. In addition to describing the guiding principles and goals of this approach, we have presented a comparison between our effort and those implemented at other colleges and universities. Furthermore, we have presented a discussion of the pros and cons of the Interactive Dynamics approach when compared to the traditional approach to teaching dynamics and we have also indicated that in assessing the efficacy of this new approach, one must include economical factors such as the cost of software, hardware, and ongoing maintenance of the Interactive Classroom. A definition of project success and the assessment of that success will be the subject of a future publication.

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