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On the Implementation of Interactive Dynamics*

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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, experiment, and teamwork in courses traditionally containing neither. We briefly describe our approach and detail some of the important issues and hurdles that we have encountered during its implementation. It is our purpose that this information will assist other educators in implementing the Interactive Mechanics concept or learning environments like it.

INTRODUCTION

INDUSTRIES are increasingly requiring that graduates in engineering have the skills needed to become immediately productive without the 'on-the-job' training that was typical of recent decades. Achieving this goal requires a clear understanding of the current as well as future job markets. In the United States, 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 [1–8] have identified as shortcomings of most of the current curricula, among other things, the lack of:

- a hands-on laboratory experience;
- a multidisciplinary approach;
- a systems perspective;
- understanding of information technology;
- understanding of the importance of teamwork.

In fact, the strategic goals set for engineering education institutions by ABET, stated in a recent report entitled 'ABET Criteria 2000' [2–5], include 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 teamwork, computation, data acquisition, data analysis, and information technology into the very process of learning.

A previous paper [9] presents our 'interactive' approach to addressing the problem of how to combine all the elements mentioned above into sophomore/junior level courses and, as an example, into the first engineering dynamics course. In this paper, we briefly describe our Interactive Mechanics approach and then present in detail the practical considerations associated with implementation of this approach in undergraduate mechanics courses at Penn State University.

INTERACTIVE DYNAMICS

We now briefly describe Interactive Dynamics, that is, the 'dynamics' version of Interactive Mechanics. We begin by looking at the traditional course as a contrast.

The traditional dynamics course

We are all familiar with the traditional 'chalk and talk' mode of teaching undergraduate dynamics. In this mode, an instructor presents three, one-hour lectures, in which he or she may have 5–10 minutes of interaction with the students 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

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semester, the students are required to take an 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;
- a hands-on or laboratory experience.

On the other hand, students are placed in a familiar environment in which they are very comfortable. The instructor is also teaching in a familiar environment and this contributes to the students feeling more at ease since the instructor generally uses the same set of notes every semester.

The Interactive 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 40–50% of the time. It is the other 50–60% 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. An Interactive Dynamics class typically begins 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 during the activity. After the introductory lecture, the activity begins.

An activity consists of a project requiring the solution of a difficult problem using teamwork, analysis, computer tools, and a written report. Activities are substantial enough such that they cannot be completed in one class period (the course meets two times per week for 1 hour and 55 minutes each time) and their completion often requires students to meet outside of class. 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 to be completed in a given amount of time and for which they have been provided 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.

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 and some simple numerical methods for solving them.
- The utility and problems associated with numerical derivatives are presented and used. In all cases where numerical analysis is used, the 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. At the end of the activity each team is required to submit a short report. There are typically five or six activities per semester so that a report is due every 2–3 weeks.

To give a picture of the make-up of an 'activity', we now present a detailed example we have used in this course.

AN EXAMPLE OF AN ACTIVITY: NUMERICAL SOLUTION OF EQUATIONS OF MOTION

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

The example activity described below emphasizes a point that is not often made in the first course in dynamics, namely that dynamics is about equations of motion and the motion over an interval of time and not about the 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 by doing an example problem, the solution of which 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. (This 40-minute introduction is the exception rather than the rule in Interactive Mechanics. Since students have had no formal introduction to these ideas, we spend more time on this topic than most others.) 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 *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 a myriad of ways of approximating the solutions to these equations.

We then present two problems:

1. An elastic pendulum: A two degree-of-freedom elastic pendulum.
2. A whirling mass in a horizontal plane: A two degree-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 (with reference to 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 free to move in the vertical plane under the influence of gravity. The mass is released from rest when the angle $\theta = 0^\circ$ 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 $\dot{\theta}$ versus θ.
6. Plot the *actual trajectory* of the mass as you would see it for $0 \leq t \leq 10$ 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 degree-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 $C = 0.3$ kg/s. 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 $5.0\,\mathrm{N \cdot m}$ 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 $y = 0$.'

We then ask the students to perform the following tasks:

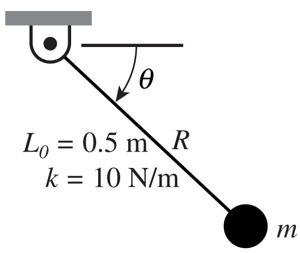

Fig. 1. Elastic pendulum described in the activity.

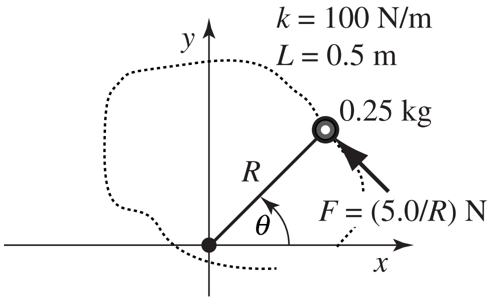

Fig. 2. Material point sliding on the xy-plane while attached at the end of an elastic rod.

1. Derive the equations of motion and state the corresponding initial conditions.
2. It will be discovered 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 $0 \leq t \leq 5$ 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 two other 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.

Pedagogical benefits of this activity

This activity reinforces and gives the students practice in the application of Newton's second law in polar coordinates and demonstrates the 'equation of motion' nature of dynamics. In addition, 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). 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.

IMPLEMENTING THE INTERACTIVE MECHANICS CONCEPT

We now describe, in detail, the problems we have encountered, the issues that have arisen, and the hurdles we have overcome in implementing our Interactive Mechanics Course. We describe all of these things with the purpose of giving other educators the benefit of our experience when implementing this educational concept or one similar to it.

Assembly of teams

The typical team in Interactive Dynamics consists of three individuals. In fact, teams consisting of two or four students are strongly discouraged. This requirement has been chosen in view of the amount of effort required to complete an activity, that is, each activity is too much work for two people. When the total number of students in the class is not divisible by three, teams of four persons are formed, four being the maximum number of students in an Interactive Dynamics team. These choices are motivated not only by didactic but also by practical reasons. In fact, the furniture with which the Interactive Dynamics classroom has been equipped makes it rather difficult for a group larger than four persons to share the physical space in front of and around a computer.

Teams are formed by the instructor during the first week of classes and are intended to remain fixed throughout the duration of the course. The forming process is not random. On the first day of classes, students are required to complete a survey, usually following the administration of the pre-test, consisting of a self-assessment of:

- mathematical proficiency;
- verbal as well as written communication skills;
- level of computer literacy or familiarity with some of the software that will be used in class during the course.

After reviewing these surveys, the instructor forms teams in such a way that each of them contains at least one member familiar with one of the skill areas mentioned above.

Despite the care exercised in the formation of teams, they may not be as homogeneous in skills as one might wish. The most likely reason for this is the fact that students tend to be over-confident when self-assessing their skills. A way to improve the method described above might be to complement the survey mentioned earlier with the student's grade point average. The student's major can also be a useful piece of information. In fact, it may help in assembling teams that are well balanced not only from the viewpoint of essential skills but also from that of *motivation*. Engineering Dynamics, i.e. the course that Interactive Dynamics is intended to improve, is a required course for most engineers at Penn State. However, not all majors perceive the Engineering

Dynamics course content as useful to them in their engineering careers. This often causes a non-negligible number of students, randomly distributed among the various sections of the course, to view the course as a 'necessary evil' that they have to endure in order to graduate. By including in teams members whose major requires the course as the basis for further curricular developments (e.g. Mechanical or Aerospace Engineering), we hope that a healthier degree of 'perceived interest' in the course is fostered.

Issues associated with activities

The essence of the Interactive Classroom is the *activity*. Activities, even when simple in concept, require a great deal of planning. In fact, several issues of diverse nature often arise and need to be confronted before an effective implementation of an activity can be found.

Each activity consists of background material, an *interesting* problem substantial enough for a team of three students to solve, and the associated web-based materials.

Creating an interesting problem that is substantial enough for a team of three students is perhaps the most difficult part of creating each activity. Of course, we must work within the constraints of the facilities and equipment available to us, but with a computer available to each team, we have found that we can make effective use of 'virtual' experiments. For example, with VideoPoint, an inexpensive software package that allows the students to obtain spatial and temporal information from QuickTime movies, the students can analyze machinery that would otherwise be inaccessible to them. Sources for activities include problems found in both undergraduate and graduate dynamics texts and problems in journals such as the *American Journal of Physics*. In fact, we have found that simply taking a dynamics problem from a textbook that asks for the motion of some system at a specific location or instant in time, and solving it for all positions and times, is often enough to create a good activity when some analysis of the results is added.

Once the activity has been decided upon, we usually like to assemble some related background material. This background material helps us provide a context to the problem proposed in the activity. This context is intended to show the students that the problems they are solving relate to larger issues which the engineering and scientific communities at large have had to solve or are still solving. Hence, the background material provides the opportunity to add a 'cultural' undertone to the students' work. We have acquired background material from many sources, including our personal libraries, the university library, and the World Wide Web. This can be a time-consuming part of creating an activity, but it really only needs to take as much time as you give it. We have found that most students don't spend much time reading this background material, but there is a minority of students who really enjoy it.

The last step is to take all of the material and create a web site based upon it. At the minimum, this task requires nothing more than either some rudimentary knowledge of HTML or a good HTML package such as Adobe PageMill or Netscape Composer. In addition, we have found that the ability to create QuickTime movies illustrating the motion of mechanical systems can be very helpful in giving the students an idea of what we are looking for—Working Model from Knowledge Revolution has been ideal for this purpose.

Software

We have already touched on some of the software packages we use for Interactive Dynamics, but we will now address the entire range of software needed to make the class work.

When choosing software tools to be used by the students, we felt that there were three factors that were most important in our decision:

1. How useful will the software be to the student after he or she graduates? That is, is the software used extensively in industry?
2. How prevalent is the software on our university campus?
3. Is the package available on all of the most popular platforms?

The answers to all of these questions should be an important consideration in deciding upon the software. In answering the first question, we drew upon not only our personal experience with software we use in our research but we also spoke with other faculty in our college and with industrial liaisons who visit our department every year. The second question was easily answered by speaking with people in our Center for Academic Computing. In an academic computing environment, the answer to the third question is not as easy as it is in an industrial setting. We have found that even though the percentage of computers running the Mac OS is approximately 10% in industry, it is generally a much higher percentage than that in academia.

In our case, we decided upon Microsoft Office for the 'productivity suite' of applications, that is, for word processing, spreadsheet, and presentation applications. It is widely available at Penn State, is used almost exclusively in industry, and is available for both Windows and Mac OS. For 'analysis' packages, we chose MATLAB and Mathematica (we also use Excel for some of the analyses we ask the students to perform). Again, both packages are cross-platform and MATLAB, especially, is used widely in industry. We chose Mathematica because it possesses symbolic capabilities that are only available in MATLAB if one purchases an additional Toolbox. Finally, even though it is not used widely in industry, we also use VideoPoint, since it is also cross-platform and allows us to perform some 'virtual' experiments that would otherwise not be possible.

Finally, we should mention that the ideal Interactive Classroom would have computer workstations for each team, each containing all the above-mentioned software and possessing a system for real-time data acquisition. In addition, the classroom would have a local high-speed network with a dedicated web and file server and a system administrator whose task is to help maintain all of this. Of course, all of this requires considerable resources and an Interactive Learning environment can be created using the web server capabilities of your college or university and a computer lab containing at least as many computers as you have teams of students.

Manpower requirements

When working on an activity in class, the students often have questions that require a great deal of attention on the part of the instructor. Questions from the various teams do not usually come in a streamlined fashion and are often posed simultaneously by various groups. Hence, it is rather difficult for a single individual to successfully assist all of the teams at once. To adequately assist roughly 10 to 12 teams, a minimum of two persons is required, although one instructor per 4–5 teams could be considered an optimal situation. Clearly, having two full-time faculty teaching the students in one class may be a heavy burden for a department to bear. The solution that we have adopted consists of utilizing the help of undergraduate teaching interns. These are students who choose to include teaching in their undergraduate experience. The teaching interns gain credit toward the completion of their degree program and, at the same time, require salaries which are usually not difficult for a department to provide on a regular basis.

The use of teaching interns in any course requires that they be adequately trained to cope with the demands of the students taking the course. In the preparation of the various activities for Interactive Dynamics, we were fortunate enough to have the resources to hire some undergraduate students during the summer. Their work in preparing and polishing the activities turned out to be an excellent training opportunity. Two of the three undergraduate assistants hired during the summer 1998, chose to extend their relationship with us by serving as teaching interns for the two Interactive Dynamics sections offered during the fall 1998 semester.

Teaching interns are not only very valuable from a 'logistical' but also from a 'public relations' viewpoint. In fact, the students taking the course see them as fellow students and are rather more prone to discuss with them the difficulties that they are experiencing, as well as opinions and suggestions on how to improve the class environment. Also, whenever interpersonal problems arise within a team, a teaching intern often has a better chance to clear up misunderstandings than a faculty person because of the age difference between students and faculty and because the teaching interns are less intimidating when discussing potentially embarrassing problems.

As a final comment, it should be noted that, despite the necessity for additional teaching personnel during classes in which there is an activity, the added instructor/student interaction does make a visible difference in student learning as well as in the instructor's awareness of the student progress. Hence, although it might be difficult at times to gather sufficient resources to hire additional teaching staff, even in the form of teaching interns, the extra effort seems to be worthwhile, both for the students as well as for the faculty involved.

Team and collaborative learning

To foster a collaborative approach to learning, students are required to act as teams in two ways. First, they are required to perform 'team activities' (discussed above). Second, every week each team is assigned a homework set consisting of three challenging problems. Although no specific instructions are given to the students on how to manage their homework assignments, each team member usually tackles one of the three problems and submits it as his or her contribution to the team.

Our original intention was for each team to distribute the three problems to the three team members. After completing the problems, we encourage the students to meet to discuss each of the problems in detail. Our hope was that the students would check each other's work, then discuss differing opinions on the solutions, and then reach a final agreement as a team. However, our experience is that we have been only mildly successful in fostering a collaborative approach to these homework problems. In fact, for a team to be successful, two conditions seem to be necessary. First, it must be relatively easy for the students to gather outside of class to work on the homework, and, second, they must be mature enough to respond to the idea that the contribution of each affects the grade of all of the team members. These considerations lead to the conclusion that the students should be given the opportunity to coordinate (if not complete) as much of their team work as possible in class. Furthermore, special attention must be devoted to the establishment of a grading policy that penalizes those who do not contribute, without discriminating against those students who, regardless of their good will, are receiving a poor team grade due to lack of care of others. A discussion of the grading policy adopted in Interactive Dynamics is presented in the next section.

Distribution of credit when grading

The overall grade assigned to each student is the result of his or her performance, both as an individual, and as a team member. The student's individual performance is measured via traditional exams and weekly homework problems. Specifically, a total of three 'midterm' exams are administered in addition to a final exam. Each of the three midterm exams contributes 10% to the overall grade, the final exam contributes 20%, and the homework problems contribute 12%. In addition, to encourage the students to collaboratively work on the homework, we give an additional 5 points (out of a possible 100) to those students whose team average homework score exceeds 90 on any given assignment. Each of the exams consists of three traditional problems along the lines of those assigned as homework. An additional fourth problem is often included to test students on some of the material dealt with during group activities (e.g. numerical analysis, interpretation of data, or presentation of data). Hence, his or her individual performance amounts to 62% of a student's final grade, thus leaving the remaining 38% to be gained through team related work.

The overall grade breakdown illustrated above is motivated by the fact that students spend a large amount of their 'Interactive Dynamics time', whether in or outside of class, dealing with team related work. We should mention that the grading scheme outlined above is the one we have settled upon after three semesters of iteration. The first semester we taught Interactive Dynamics, the activities counted for 50% of the grade. On the other hand, we also required the teams to write a full report for each activity. Thus, the overall grade was structured to reflect the proportion of time spent dealing with team activities. Unfortunately, this grade breakdown presents some potentially serious shortcomings. First of all, it should be noticed that it was possible for a student to get 100% on all of the exams and, at the same time, fail the course if no team related credit was earned. This basic observation, whether or not accompanied by considerations concerning the experimental nature of Interactive Dynamics, was at odds with how the traditional sections of Engineering Dynamics are managed. Hence, it was not uncommon that some students, especially if very bright and independent, would complain that their overall grade was actually being negatively affected by the team activities. This problem took on pathological proportions if the bright student happened to be in a dysfunctional team in which the other team members were not pulling their weight. By the same token, it was possible for a mediocre or a poor student to receive a good grade thanks to the work of others. (On the other hand, part of the motivation behind the inclusion of teams in Interactive Mechanics is the idea that teams help good students by putting them in an environment where they 'teach' poorer students and teams help poorer students by putting them in an environment in which they are being helped by the better students.)

In addition, we quickly discovered that we were asking the students to do four or five credits worth of work in a three-credit course. Therefore, we have changed the amount of credit associated with the activities to the current 38% and now require only one or two full reports per semester. This still leaves many of the problems associated with teams that we mentioned above. Hence, in order for our grading policy to reward hard work and good work it must be complemented by the instructor's discretion in assessing who is actually doing the work during the team activities. For this reason, the 38% of their grade, which is associated with team activity, is actually referred to as the Individual Activity Grade (IAG) and this differs from what we call the Team Activity Grade (TAG). The TAG, which is the same for each member of a team, is the grade given to any activity report or homework. Each student's IAG is determined using the simple relation that $\text{IAG} = \text{TAG} \times \text{IAF}$, where IAF refers to an Instructor Assessment Factor and it is a number ranging from zero to 1.25. Setting the IAF lower bound to zero is intended to serve as a deterrent against 'free-loaders'. The IAF upper bound, set to 1.25, has been chosen to indicate that the instructor does not have 'absolute power' in increasing the grade of an individual. This limit on the instructor's power is intended to be a deterrent against those students who may dislike team work up to the point of 'sabotaging' their team and rely solely on their exam scores. The IAF is chosen based on our observation of students and teams during the semester and on confidential peer evaluations that are completed by each student after each activity. The peer evaluations allow each student to evaluate the work of his or her team members and to comment on the fairness of the division of labor during collaborative work. With all of this mind, we should mention that for nearly all students, the IAF will be chosen as unity. In fact, during the three semesters we have taught this course to more than 150 students, we have never given a student an IAF less than 0.85.

The grading policy described above is rather complex and it relies heavily on the instructor's awareness of the work ethic and 'sociological health' of each of the teams. It should be mentioned that Interactive Dynamics has not been taught long enough to assess the effectiveness of this grading scheme and, for this reason, no claims are made to its fairness or success in promoting collaborative learning. To date, we can only report that a fair and honest grade has been assigned to the students who have taken this course and that this grading policy has allowed us, the instructors of Interactive Dynamics, to resolve every controversy that has arisen within the various teams in our course.

Presentation of results

Every activity culminates in the compilation of a written report. From an educational viewpoint, these reports are intended to instill in the students the idea that good communication skills, written communication in particular, are extremely important in the engineering profession. From a more technical viewpoint, these reports are intended to impart on the students a few basic ideas on how to logically present technical information, with the hope that, in so doing, they will also learn how to read a report and decode the information contained therein. The creation of a technical report also forces the students to think deeply about their results and to interpret them before going on to their next task. In order to facilitate this learning process, the students are supplied with a Microsoft Word template created by the instructors.

This template is also a sample report structured in 5 basic parts:

1. an abstract
2. an introduction
3. a methods section
4. a results and discussion section
5. a conclusions section.

If necessary, appendices are used to describe additional material that would otherwise make the body of the report difficult to read.

Since we have provided the students with this template, the main effort required of the students is that of creating the content of the sample report rather than having to focus on the format. On the other hand, since they have been provided with a professionally formatted report, it is hoped that they will learn by example what a report should look like and what it should contain. As part of this, the students are required to present their results using graphs and tables that must be formatted and displayed in a professional style. By 'professional' we mean that a figure or a table must be provided with a numbered label, which is then followed by a caption. The latter must be a short but representative explanation of the information reported in the figure or table. When discussing their results within the text of the report, the students are required to refer to figures and tables using the appropriate labels.

All of these requirements on figure and tables are intended to correct from the very beginning a phenomenon that the authors have observed in first time report writers, that is, they write '. . . as can be seen in the figure . . .' when the figures in the report are not numbered or provided with a caption, nor the information discussed in the text appears in any of figures displayed.

The emphasis of Interactive Dynamics is not and should not be on writing since it is not a writing course. Thus the emphasis placed on the report style is minor when compared to the emphasis placed on the solution of the activity problems. In other words, the students are left to learn about report writing from the example provided by the template given to them at the beginning of the semester. For this reason, the template not only contains a sample report written by the instructors but it also contains a succinct report grading scheme which outlines the various sections of a report, giving a synopsis of their intended purpose as described in a manual of technical writing style being used at Penn State [10]. From a grading viewpoint, regardless of how badly written a report may be, more than 65% of its grade value is usually given to the students as long as the results reported therein are correct.

Making Interactive Dynamics sustainable

As we have argued in an earlier paper [9], the success of Interactive Mechanics depends on a careful assessment of whether or not the course is doing what we intend it to, namely, to better teach students mechanics and to begin to give them some of the skills they will need in the workplace. In addition, it will not be a success if we do not make it sustainable and part of the infrastructure of the mechanics curriculum at Penn State University. To do this, we need to not only demonstrate that Interactive Mechanics works, but to convince our faculty that it is something that they should all be doing. In order to do this, we have begun creating the materials needed to make the transition for those faculty who wish to adopt this teaching style as painless as possible. For example, our activities are organized on the web server by topic and are accessible to faculty via a password protected web page that allows them to determine their next activity using a tree-like structure which is organized by topic. This makes it easy for an instructor to find out which activities are available on the next topic as that topic approaches in the course calendar. We are also creating a comprehensive Instructor's Guide containing detailed descriptions, possible solutions, learning objectives, common misconceptions, and a list of frequently asked questions for each activity. The Instructor's Guide will also contain information such as:

- tips and techniques for choosing teams at the beginning of each semester;
- tips and techniques for handling team-related problems during the semester;
- suggested grading strategies for courses containing extensive team-based activity such as this one;
- a possible syllabus, along with a timeline to guide the instructor through a semester.

It is our eventual goal to make Interactive Dynamics the sole means of teaching the first course in dynamics at Penn State University. Therefore, not only will we need resource materials for new instructors such as those described above, but we would also like to be able to introduce new faculty to Interactive Dynamics/Mechanics by team-teaching with them for a semester so that they can learn by watching. This would allow new instructors to have a 'transition period' during which they are involved in the course but do not have all of the responsibilities associated with teaching a section on their own.

CONCLUSIONS

In a previous publication [9] we have presented the theory and pedagogical philosophies behind the Interactive Mechanics concept. In this work we have presented some of the 'nuts and bolts' details associated with implementing a new teaching philosophy such as this. In doing so, we have tried to address many of the issues and questions that would arise if a faculty person at another college or university were to attempt to teach in this 'Interactive' way.

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REFERENCES

1. *Shaping the Future*, A report on the review of undergraduate education from the Committee for the Review to the National Science Foundation Directorate for Education and Human Resources, **NSF 96-139** (1996). Available at the following WWW site: http://www.ehr.nsf.gov/EHR/DUE/documents/review/96139/start.htm.
2. *ABET Engineering Criteria 2000, Third Edition* (1997). Available at the following WWW site: http://www.abet.org/eac/eac2000.htm.
3. *ABET Mechanical Engineering & Engineering Mechanics Criteria* 2000 (1998). Available at the WWW site: http://www.asme.org/educate/abet/progcrit.htm.
4. *ABET 2000 Program Criteria: Materials and Metallurgy* (1998). Available at the following WWW site: http://www.tms.org/Education/ABET2000.html.
5. M. S. Wald, Engineering criteria 2000, *Int. J. Eng. Educ.*, **12**, (1996) pp. 389–390.
6. R. A. Behr, Concurrent structural analysis and experimentation using the 'AN/EX' Mini-Laboratory, *Comp. App. Eng. Educ.*, **1** (1993) pp. 213–222.
7. R. A. Behr, Computer simulations versus real experiments in a portable structural mechanics laboratory, *Comp. App. Eng. Educ.*, **4**, (1996) pp. 9–18.
8. R. Butterfield, Benefit without cost in a mechanics laboratory, *ASEE J. Eng. Educ.*, (October 1997) pp. 315–320.
9. Gary L. Gray and Francesco Costanzo, On the concept of the interactive classroom and its integration into the mechanics curriculum, *Int. J. Eng. Educ.*, 15 (1999) pp. 41–50.
10. Joe Schall, *Style for Students: Effective Writing in Science and Engineering*, Burgess Publishing, Edina, MN (1995).

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