Assessing News Ways of Teaching Dynamics: An Ongoing Program to Improve Teaching, Learning, and Assessment

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Abstract

In spring 1998, a traditional lecture and problem-solving based course in introductory dynamics was infused with interactive learning activities. The enhanced course called "Interactive Dynamics" was designed to engage students in a collaborative environment in which students have easy access to an array of technological tools (web-based simulations, spreadsheets, computational and simulation tools, etc.). They used these tools to generate and analyze data, observe graphic representations of the data, and construct and interact with simulations.
To assess the innovations introduced into this course, we conducted pre- and post-tests on dynamics content in the Interactive sections and in the control (traditionally taught, lecture-style) sections of the course. Additionally, we collected data for other learning objectives congruent with ABET (Accreditation Board for Engineering Technology) 2000 Criteria, *e.g.*, teamwork, problem solving, communications, and computer skills. While gains in mechanics content knowledge for students in innovative sections were similar to those of students in traditional sections, students in active learning classrooms reported statistically significant gains in teamwork and computer skills. The data indicate the new course design reinforces the ABET goals of encouraging innovative practices in the classroom that enhance learning and develop skills needed in the workplace.

This paper addresses several issues: (1) how do we develop measures that accurately reflect learning objectives given the innovative teaching practices, (2) what learning outcomes are affected when active learning strategies are employed in the engineering classroom, and (3) how can we use these assessments to improve teaching, learning, and assessment in future semesters? We used the data to enhance activities and assessment for classes being taught during fall 1998 and continue to look for ways to improve the teaching and assessment process.

1 Introduction

It is becoming increasingly important that graduates in engineering have the skills needed to become immediately productive without the "on-the-job" training that has been typical of recent decades. In order to achieve this goal, engineering educators must have a clear understanding of the current as well as future job markets. In the United States, accreditation boards such as ABET [1], agencies such as the National Science Foundation (NSF) [2], and major corporations such as Boeing [3] play an important role in discerning these needs. Therefore, they offer a "vision" that allows one to set the correct strategic goals. In fact, the strategic goals set forth for engineering educational institutions by ABET, as stated in "Criterion 3: Program Outcomes and

Assessment", in a recent report entitled "ABET Engineering Criteria 2000", says that engineering programs must demonstrate that their graduates have such skills as [2, 4]:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as to analyze and interpret data;
- an ability to function on multi-disciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an ability to communicate effectively;
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

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 of, 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.

At Penn State, we have begun to offer sections of introductory dynamics in a manner that begins to address many of the desires expressed by ABET, NSF, and others. In a previous paper [5], two of the present authors (Gray and Costanzo) present their "Interactive" approach to addressing the problem of how to practically combine all the elements mentioned above into sophomore/junior level courses. The implementation of their approach into dynamics has been dubbed *Interactive Dynamics.*

1.1 Teaching Dynamics

Magill [6] suggests that dynamics is "one of the more difficult courses that engineering students encounter during their undergraduate study." One reason for this is that dynamics material has traditionally been taught without discussing the concepts in a meaningful context. It is an objectively complex course requiring both a solid understanding of basic physics *and* an intuition regarding solution strategies. In other words, dynamics problems are such that a well-defined solution protocol applicable in all cases cannot be provided. One way around these difficulties is to teach dynamics using workplace-derived problems and solution protocols as recommended in the ABET 2000 criteria described above.

While some faculty have responded to the inherent difficulties of teaching and learning dynamics by adopting procedural problem-solving methods [6, 7] others have applied a variety of active learning approaches in dynamics (and statics) classrooms [8, 9, 10, 11]. Asokanthan [8] for example, reports on the use of simulations using software, physical models, and videos to involve students in the learning process.

1.2 Interactive, Student-Centered Learning

> "Student-centered instruction is a broad teaching approach that includes substituting active learning for lectures, holding students re-

> sponsible for their learning, and using self-paced and/or cooperative (team-based) learning" (Felder and Brent, p. 43). [12]

Meyers and Jones [13] describe active learning as a way to provide "opportunities for students to *talk and listen, read, write, and reflect* as they approach course content—all of which require students to *apply* what they are learning" (p. 1). Active learning encompasses a wide variety of strategies including problem-solving exercises, informal small groups, cooperative work, simulations, case studies, role playing, and journal writing [13]. With active learning, "students are more likely to internalize, understand, and remember material learned through active engagement in the learning process" [14, p.3]. Interactive dynamics is one of several instances of applications of active learning techniques in engineering [15, 16].

1.3 Interactive Dynamics

At Penn State, dynamics has always traditionally been taught in "chalk and talk" mode, where mode, an instructor presents three, 50-minute lectures per week. Five to ten minutes of a class period may include interaction with the students in the form of questions and answers. Otherwise, students passively take notes on theory and example problems presented by the instructor. The class is usually structured so that the students do required homework problems out of the text and take exams two or three times per semester. By teaching a course in this manner, students do not participate in any of the activities deemed important in the modern engineering workplace. On the other hand, students are placed in an almost anonymous but familiar environment in which they appear to be very comfortable. The same can be said of the instructor in that his or her role is limited but rather well defined and this contributes to students' feeling of ease.

Similar to a traditional dynamics class, the typical Interactive Dynamics class assigns homework problems, has two or three midterm exams per semester, and even uses basic lectures 40–50% of the time. It is the other 50–60% of the class that profoundly distinguishes Interactive Dynamics from traditional dynamics. An Interactive Dynamics class typically begins with a 15–45 minute introductory lecture in which the instructors present the goal of the day's *activity*. This introduction is intended to (a) point out important things students should look for during the activity and (b) provide a context for the students' work so that they see that what they do in class is indeed related to "real-life" problems. After the introductory lecture, the activity begins.

An activity consists of a project requiring the solution of a difficult problem. The complexity of the problem is such that its solution requires the use of teamwork (students work in teams of 2 – 3), analysis and computer tools. Students summarize their process and solutions in a written report. Activities are substantial enough such that they cannot be completed in one class period (classes meets for 1 hour and 55 minutes two times per week). In addition to the "dynamics" problem, each activity requires students to use a certain tools (*e.g.*, Excel, VideoPoint, MATLAB, Mathematica, the Internet, rulers, and scales). Instructors do not "take the students by the hand" as they work their way through each activity, that is, students may be required to learn some (easily accessible) material which is not entirely described during lectures, *e.g.*, computer application skills. This educational environment is intended to make the process of completing each activity to be as "real-world" as possible. That is, students are encouraged to be actively engaged in their problem-solving while the instructor plays the role of listener, mentor, and advisor. Typically, there are five to six activities per semester.

Every activity is based upon dynamic's fundamental theme of finding equations of motion and loads on systems for the purpose of design. In other words, instructors strongly de-emphasize the notion, almost universally espoused in undergraduate dynamics, that students should only analyze certain characteristics of the system at a specific point in space or time. An additional objective is the development of those skills that allow an individual to be productive while working, such as taking on or assigning 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, as compared to traditional dynamics, Interactive Dynamics students are introduced to many "accessory" concepts (*e.g.*, ordinary differential equations, simple numerical analysis, numerical error, trajectories of differential equations, equilibrium and steady-state solutions, technical report writing skills, the scientific method and the science and art of engineering, measurement error, visualization).

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.

2 Assessing Student Learning

> "Assessment is not just about looking for answers…the process of formulating the questions about learning to be researched, or of more precisely defining the outcomes that instruction is supposed to produce, is often as valuable in suggesting improvement as the information that eventually results." (Ewell, p. 107) [17].

Good assessment practice includes the measurement of "input," "environment," and "outcomes" [18]. In order for the assessment to have an impact, we need to follow the three basic steps in assessing student learning. These are:

1. Defining goals and objectives,
2. Developing measures of the objectives, and
3. Using the results to improve the process [19].

2.1 Defining Goals and Objectives

To begin the assessment process the authors revisited the goals and objectives for Interactive Dynamics. We spent considerable time discussing one essential question: what do we expect the students in this class to come away with over and above what they would get in the traditional dynamics? As Ewell [17] suggests, the discussion of goals to assess was an integral part of the process and was instrumental in helping develop the course design. The essential goals and objectives for the Interactive Dynamics class were:

- content knowledge,
- teamwork skills,

- computer literacy skills, and
- technical writing skills.

The primary goal for the course was that the dynamics content, *i.e.*, subject matter learning, would be mastered equally or better than in traditional courses. Given the research that suggests that students learn better when they are actively involved in the classroom [16], we hypothesized that students would develop a richer understanding of the principles of dynamics in the Interactive course than they would in the "chalk and talk" classes. Secondary goals of the interactive, team-based nature of the course were to provide students with an opportunity to develop their communications, technology and group skills

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> "Assessment is not about measuring everything. Instead priorities for collecting information in any context should be driven by a set of clear priorities, themselves established by faculty and key constituencies." (Ewell, p. 107) [17].

We developed the initial assessment plan in conjunction with the first offering of Interactive Dynamics. Given limited resources, not all of the learning outcomes described above could be fully assessed. We made assessment decisions by prioritizing outcomes and assessing the essential outcomes expected for the course. Faculty often express concern that the inclusion of active learning activities comes at the expense of content. In order to determine whether this is true for this course, content was the first priority for assessment. Demonstrating that students were indeed mastering the content would be an important factor in being able to extend this type of instruction to other classes. Therefore, content learning was the first priority for assessment.

2.2 Developing Measures for the Objectives

This section describes measures used to gather data on the multiple objectives described. For all measures, we collected data during the spring 1998 semester from two sections of Interactive Dynamics (55 students total), and four sections (176 students) of traditionally taught dynamics courses.

2.2.1 Content Learning

To measure content learning, the instructors developed a single test that was given both during the first and last weeks of the semester. The content learning objectives for the course include analysis of motion articulated into two parts: kinematics and kinetics. Within kinetics, three principles were emphasized: Newton's second law (i.e., $\vec{F} = m\vec{a}$), the impulse-momentum principle, and the work-energy principle. To clarify these objectives, the instructors compiled a list of concepts students are expected to know upon completion of a dynamics course. Test items on these concepts were drawn primarily from the Mechanics Baseline Test [20] and the Engineering GRE. Items intended to measure prerequisite knowledge in physics and mathematics were also included. For example, the pretest included several items on one-dimensional kinematics, algebra, and calculus. In total, 31 multiple-choice items were included on a 30-minute exam.

2.2.2 Teamwork, Computer, and Problem-Solving Skills

Since the "non-content" goals were an integral part of the Interactive Dynamics learning goals, we searched for ways to best measure these outcomes. An instrument developed for the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) project, the Classroom Activities and Outcomes Survey [21], contained items covering the objectives we were attempting to measure. The instrument had the advantage of having been pilot-tested at multiple institutions. The questionnaire contains a variety of items and scales to provide student self-assessment of attitudes and abilities on collaborative learning, problem-solving, interaction with faculty and peers, engineering design, and communication skills. Items measuring students' confidence and motivation to become an engineer and perceptions of their computer skills were also included. Students completed this instrument once at the end of the semester.

2.2.3 Other Measures

Additional information was obtained by modifying existing feedback mechanisms. Penn State has a program to collect Student Ratings of Teacher Effectiveness (SRTE). Items were added to this instrument to obtain anonymous input from students on their satisfaction with the weighting of assignments toward the final grade and the mix of lecture and activities.

2.3 Using the Results to Improve the Process

The assessment results had an impact on both our assessment plan and the course itself for the following semester. We begin by examining the results of students' content learning.

2.3.1 Content Learning

Students' performance on the pre- and post-test indicated no real differences in gains in subject matter learning between students in Interactive Dynamics or the "traditional" classes. Further analysis of the exam revealed that some concepts that had been stressed throughout the interactive dynamics course were not assessed. Additional items were added and are currently being tested to see how well they measure student performance. Also, a few items on which students scored high on at the beginning and end of the semester were removed from the exam.

Some pre-test/post-test item results were disappointing. For example, gains on some essential concepts were almost negligible, certainly not the gains expected after a semester of activity and constant discussion. After reviewing the revised exam and concurring that it did address concepts aligned with the course goals, the instructors – together with a college pedagogical expert – devised pedagogical methods to help improve students' understanding of these concepts. These methods are currently being tested.

2.3.2 Teamwork, Computer, and Problem-Solving Skills

Unlike content learning, students showed large differences in their self-reported improvements in teamwork and computer skills. This is encouraging, not only because of the emphasis being placed on these skills by external and internal constituencies, but also because students felt so positively about the impact of Interactive Dynamics on their teamwork and computer abilities. Interactive dynamics will continue to encourage development in these skill areas.

2.3.3 Other Measures

SRTE scores and comments indicated that students were dissatisfied with the weight being placed on the activities associated with Interactive Dynamics. While they were spending a tremendous amount of time on their projects (something not required of students in traditional classes), the activities were only assigned 15% of the grade. Because students felt the activities should be worth closer to 50% of the grade, and the scheme has been adjusted to better reflect the amount of effort students put into the activities.

3 Future Directions

In light of the "changed view of the teaching-learning process," Ewell [17] notes a "growing emphasis on constructing methods aimed at documenting instructional processes and behavior in conjunction with measuring outcomes." (p. 110). The pre and post-test we developed is a standardized, multiple-choice instrument, emphasizing traditional dynamics skills. While it is important to be able to demonstrate that student learning has not been adversely affected by the inclusion of activities in the course, it would be desirable to develop more naturalistic assessments of the learning that is being facilitated in the Interactive Dynamics classroom.

For instance, to get beyond students' self-reports of improved writing skills, during the fall 1998 semester, we collected writing samples at various intervals throughout the semester. A panel of experts is examining them to determine whether writing skills are improving on a number of criteria. Such data will, if they prove to be positive, provide a stronger case for the course's effectiveness in this area. Another, more "naturalistic" assessment would be to directly test students' ability to solve open-ended problems similar to those emphasized in the activities. Testing students' ability to solve such open-ended problems (as compared to a control group) would provide data that we currently are not getting from the traditional problems on the pre post test. This assessment enhancement is currently being considered.

An important part of the assessment process has been the ongoing gathering of student feedback. Interactive Dynamics faculty routinely meet with the students in the class to hear students' opinions of how things are going. In addition, two undergraduate student teaching interns routinely meet with students and relay concerns to the faculty anonymously. In the best of all possible worlds, we would interview students as part of the formal assessment process, but budget and time constraints prohibit this. We are exploring the possibility of using open-ended questions and other classroom assessment techniques (minute papers) [22] to systematically gather qualitative information from students.

Finally and most importantly, the pre-post test results indicate that students are not making the leap between the activities and the broader conceptual understanding we want them to ascertain. We are looking into the possibility of using concept-mapping techniques to bridge this gap. While we are pleased with the development of teamwork and computer literacy skills, we do not want to overlook the goal of deepening students' conceptual understanding of dynamics.

4 Conclusions

> "Assessment resembles scholarship in the fact that it is never really completed" (Ewell, 1998) [17].

Assessment is necessary to check the effectiveness of newly implemented pedagogical changes. At the same time, it drives the refinement of not only future assessment techniques but also teaching and learning improvements. If we had not engaged in the assessment process described in this paper, we would not know many things that are critical to the improvement and success of this pedagogical innovation. Our initial results show that students in the interactive sections have improved computing and teamwork skills, but their grasp of dynamics concepts is no better than students in the control sections. This tells us that while some of the ancillary goals of the course are being met, and while students are doing no worse on dynamics concepts, we must modify and improve our pedagogical techniques to help students attain the deeper conceptual understanding we desire. The assessment process for Interactive Dynamics has been a very rewarding experience in what Boyer and others [23, 24] call the "scholarship of teaching." By continuing to collect and analyze these data, we hope to provide a better experience for our students – which after all is our most basic goal.

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