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DYNAMICS AS A PROCESS, HELPING UNDERGRADUATES UNDERSTAND DESIGN AND ANALYSIS OF DYNAMIC SYSTEMS

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ABSTRACT

Although the first course in Engineering Dynamics often occurs early in the undergraduate career and most faculty call the material fundamental, it is neither easy to teach nor to learn. This paper proposes what might be a better method of teaching Dynamics. For the reader who teaches undergraduate Dynamics, this paper will provide detail about how to teach the class. For other readers, the contribution is to suggest, and demonstrate with results from one class experiment, that Engineering Analysis can be taught effectively by concentrating on process.

The essence of the method is to teach Dynamics as a problem-solving process. By teaching process rather than facts, students build links between equations and Engineering. Students develop an understanding of why things act as they do, why assumptions are made and when they are valid. This understanding allows them to handle more general problems without having specific examples to mimic.

This paper outlines a Dynamics class that accomplishes the following:

1. Addresses a student's mistaken intuition by confronting these mistakes and reasoning why the error was made.
2. Provides the student with a process for real-world problems. Here, real-world is defined as problems in which assumptions have to be made, tested and solutions verified.
3. Provides the student with design rules and the clear distinction between these rules and rigorous analysis.

The class has been taught once and results show that students can learn to work tough dynamics problems. Students perform exam problems “unlike” homework demonstrating they have understood concepts and principles. Results in follow on classes are inconclusive at the present time, but suggests the knowledge is retained better.

INTRODUCTION

The author's experience has shown that even graduate students with an excellent undergraduate record from top schools can be operationally ignorant when dealing with out-of-the-ordinary dynamics problems. The students have several conceptual problems when they attempt to define coordinate systems which are not standard. For example, they have difficulty when the "ideal" coordinate system to choose is not polar, rectangular, path, or spherical. Many graduate students demonstrate a lack of long-term memory committed to Dynamics and often have to review extensively at considerable cost.

The Importance of Process

Because Dynamics is an important fundamental course on which many other subjects will build, it is essential to get students to move the information from their short to their long-term memories. There may be a number of ways to accomplish this. This paper discusses a class built around two concepts: advanced organizers, and procedural, or rule based, problem solving.

Advanced organizers, like educational objective statements and an organizing procedure, are a form of Metacognitive strategy[1]. The objectives allow the student to think about the material before learning it and the procedural organization allows the novice to fit pieces of knowledge into a more complete world view. Advanced organizers, according to Chiquito[1], facilitates the transfer of information into the long-term memory by relating new information to preexisting knowledge.

Other studies show similar results. Vadhan and Philip[2] explain that cognition is acquired knowledge and metacognition is awareness and thoughts about the acquired knowledge. Their studies indicate that students with higher metacognitive skills generally obtain higher grades. They suggest that these metacognitive skills allow the students to understand what is expected of them and to be self-aware of whether they meet expectation. It is not clear from their work whether the high-achieving students had better metacognitive skills because they were good students or that they were good students because they had metacognitive skills. In any event, it seems obvious that having the ability to think about what you know is a desirable life-long self-improvement skill. The educational objectives and structure presented for Dynamics is one method of helping students develop metacognitive abilities in the subject of Dynamics.

Recent work by Anderson and Fincham[3] reinforces what many Engineering educators have believed for years: that students tend to learn technical subjects by comparing with examples. Earlier work by Novick and Holyoak[4] reached the same conclusion. They demonstrated that, when in the example-matching mode of problem-solving, student performance improved if one told the student which example was most like the current problem. No wonder many (if not most) undergraduate engineering textbooks are clearly laid out with little compartmentalized examples followed by similar homework problems. Again it is not clear what is the cause and what is the effect. Do students learn material by example because that is what the texts and their teachers encourage, or do the texts and teachers follow the most natural learning process of students?

This question may be moot since Anderson and Fincham as well as Novick and Holyoak point out that their subjects gradually moved from an example mode of problem solving into a procedural one. In fact, Novick and Holyoak suggest that making this switch is critical when they report that a good predictor of future success is the ability to state a rule for solving a problem after an initial example.

If procedural or rule based problem solving is important, is it necessary to provide students with the rules? Clearly the answer is no. It is possible for students to develop their own rules. Lewicki, Czyzewska and Hoffman[5] demonstrated that subjects could, it seemed, devise complex rules for predicting the outcome of perception tests. Though it is not clear that their experiment applies to technical problems, it, combined with practical teaching experience, suggests that students can develop their own procedures.

In light of these studies, it seems reasonable that a procedural method of teaching Dynamics would:

1. facilitate commitment of the information to long-term memory,
2. facilitate conversion from example-matching to true understanding of the material,
3. result in greater performance by the students.

Changing the way the material is presented is only one of the important alterations needed. Attention must also be placed on what is taught. What we want is to teach students, or rather give students practice with the truly high levels of thinking[6] and not bore them with the mundane. For example, we want students to "formulate" problems, to be able to ask the right questions and know how to respond to the answers. The students should know as much about why something is done as they do about what is done. Only by understanding why will they deal effectively with unique situations.

A simple example of this concept in Dynamics is the case of belts and pulleys. Give a group of students an automobile engine running at constant speed, point to a fan belt and several pulleys under the hood. Let one of the pulleys be driving the fan or water pump and another be an idler pulley. Ask the students to draw freebody diagrams of the pump and idler pulleys. My hypothesis is that most of them will show equal tensions on either side of the pulley. Ask them why and they respond with something like, "Tension on either side of a massless frictionless pulley is the same." This is of course wrong, what the students are demonstrating is an application of a memorized rule and not the application of a concept. They should apply the concept of equilibrium to arrive at the conclusion that the idler pulley has approximately equal tensions but the pump does not. What this indicates is that providing "handy dandy" rules and formulas, especially early in the course material can have a devastating effect. I suggest that by teaching process, rather than formulas, this difficulty and others can be avoided.

Another area in which students are weak is design of Dynamic systems. The skills required for design are duals to those needed for analysis. For example, in analysis, one generally tries to make as few assumptions as possible then determine the resulting behavior. In design, one often makes many simplifying assumptions then applies intuition and memorized facts to reason what might happen. To be an effective designer one must have a ready supply of facts and correct intuition. The problem for the instructor is to make sure these "facts" and intuition are correct, and organized in some way to enable students to recall them. Hence a process is important.

Finally, the current textbooks pose a real problem. Most texts are a collection of facts. For example, equations for rectilinear motion with constant acceleration are boxed and kinetics of a single rigid body rotating about a fixed point are separated from those for translation and general plane motion. Students learn quickly (and incorrectly) that Dynamics is a process of identifying the correct facts then applying the correct equation to compute some other desired fact. Likewise rather than incorporating work-energy methods into an overall scheme, they are often presented and treated as totally different methods of formulation exacerbating the faulty idea that there is a special equation for every case. In reality, work-energy can be thought of as an alternative method for relating force to motion and has a tie to all other problems. Impulse-momentum methods can be viewed as a method for handling complex forces which again leaves it potentially applicable to all problems.

The Dynamic Process

The process used for dynamic analysis consists of six major steps with some minor details in each step. The way the process is used in class is the six steps are listed early in the semester with very few details. Every new topic is placed in perspective using the process. As the semester progresses, the students obtain a more detailed perspective of the process. As new material is introduced, the process expands and remains expanded showing all the detail up to the current time. Since the present audience is most likely familiar with dynamic analysis, the entire process is listed here. Due to space limitations, the details are omitted. Detailed discussion of each step, examples of each one, and the course sequence for the class can be found by browsing the author's web site.

The Process for Dynamic Analysis

1) Think About the Problem.
    - Identify what is known, what is needed and what kind of solution is expected.
    - Count the "Degree of Freedom'"
    - Make necessary assumptions about the problem.
    - Decide what assumptions to test first.
2) Choose Coordinates.
    - Select variables, or coordinates, that will describe the object's "motion."
    - Decide if the problem requires a "Force-Motion Relationship", discussed shortly, or if it is merely a "Kinematic" (relate motions only) problem.
3) Define the System.
    - Determine what type of "Force-Motion Relationship" is needed.
    - Determine how many objects or bodies you can expect to isolate and study. Typically you would **study** each object in the problem only once. So if there are three objects, you would expect a maximum of three isolated objects to study.
    - Decide what object or body to study.
    - Decide how to isolate objects "wisely."
    - Draw a freebody diagram or "state diagram".
4) Apply a Force-Motion Relation. I use two "laws", Newton's and Work-Energy. At this point, students compute acceleration (if required) and set it equal to forces. They perform

the analogous operations for moment and work-energy. They understand that regardless of how they labeled motion variables, they must compute inertial motion.

5) Find "Extra" Equations.
   - Find more objects to isolate and study.
   - Relate motions "kinematically." This involves thinking about the degrees of freedom and the information given in the problem statement.
   - Find other relationships peculiar to the particular problem. As an example, the coefficient of restitution is extra information that describes the material behavior during collisions.
   - Determine if the problem is ill-defined. If so, pose it differently.
6) Solve and Interpret. The solving step is relegated to computer tools whenever possible, but the students are often asked to interpret the solutions.
   - Determine the required solution. Most dynamics problems have one of three types of solutions. These are:
     ⇒ Given the motion NOW, determine some force NOW.
     ⇒ Given force, solve a differential equation for motion in the future.
     ⇒ Given a certain status NOW, solve a differential equation to find the status in the FUTURE. For example, determine the maximum force in an engine as it operates.
   - Verify all assumptions. Students recognize that many assumptions involve assuming a constraint on a force or its corresponding motion. They learn to verify these constraints.
   - Check to see that the solution is reasonable.

RESULTS

The process described in this paper was implemented in an undergraduate sophomore dynamics class of fifty students at Texas A&M in the Spring term 1996.[*] The class is required of many engineering majors at Texas A&M. Typical of tough required classes, student classifications ranged from second term sophomores to graduating seniors. Of the 50 students enrolled, 2 dropped out by the end of the first week. I attribute that to the fact that the students were told the class would be "out of the ordinary," which is disturbing to many students.

Overall, the 48 students remaining in the class performed very well. The failure rate (D and F) was significantly below the average for other sections and there was a general sense of enthusiasm. The class attendance was always above 80%. Much of the time, attendance was very near 100%.

The class is sufficiently different that it takes time for the students to adjust to the process-oriented thinking. One individual after the second exam made the following comment: "On problem XXX, I was lost. I didn't have a clue so I applied the process and it worked out real easy."

The examinations were restricted to well defined problems. The problem statements left little to the student's imagination. Since vaguely worded and open ended problem statements often generate many possible responses, I made an effort to force the solution of a specific problem by wording it appropriately.

None of the examination problems looked even remotely like any homework problem or any example in the textbook. The exams were open book because open book exams tend to discourage memorization.

Since it is possible to obtain high grades with an easy exam, the reader needs to evaluate the level of difficulty of the exams. The final exam given to the class can be found at the author's web site.

Five of the students studied enrolled in and completed a second (follow on) dynamics course. The performance of these students in the second course was compared to the performance of their classmates in the second course. An ANOVA test was performed on the student performance. The 5 students under study achieved an exam average in the second dynamics class of 66.6 compared to their 52 classmates in the second class who averaged 64.8. The F value for testing the null hypothesis that the averages are the same was 0.087 providing a P-value of 0.76. Clearly the difference in the means are not statistically significant due to the small sample size. The test does however favor the 5 students under study.

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* For those who desire to teach a similar course, please contact the author for information about teaching resources.