# AC 2010-2141: DEVELOPMENT AND IMPLEMENTATION OF CHALLENGE-BASED INSTRUCTION IN STATICS AND DYNAMICS

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# Development and Implementation of Challenge-Based Instruction in Statics and Dynamics

## Abstract

This paper discusses challenge-based instructional (CBI) materials developed for courses in Statics and Dynamics. This effort is a component of a funded College Cost Reduction and Access Act (CCRAA) grant from the Department of Education, and focuses on student retention and development of adaptive expertise. Studies have shown that minority science, technology, engineering, and math (STEM) students leave STEM undergraduate fields in part due to lack of real world connections to their classroom learning experiences. Furthermore, in STEM fields the conventional approach is to teach for efficiency first and for innovation only in the latter years of the curriculum. This focus on efficiency first can actually stifle attempts at innovation in later courses. Our response to these issues is to change the way we teach. CBI, a form of inquiry based learning, can be simply thought of as teaching backwards. In this approach, a challenge is presented first, and the supporting theory (required to solve the challenge) second. Our implementation of CBI is built around the How People Learn (HPL) framework for effective learning environments and is realized and anchored by the STAR Legacy Cycle, as developed and fostered by the VaNTH NSF ERC for Bioengineering Educational Technologies. The developed materials are a result of collaboration between faculty members at the University of Texas-Pan American (UTPA) and South Texas College (STC), a two year Hispanic Serving Institution (HSI).

## 1. Introduction

### 1.1 Overview of Supporting Grant

This work reported in this paper describes results of one of the ongoing activities of an integrated STEM pathways support initiative for the Rio South Texas Region. This initiative is a collaboration between UTPA and STC to facilitate student engagement and success in STEM areas. With funding from a College Cost Reduction and Access Act (CCRAA) grant from the Department of Education, the two institutions are developing and supporting strategies that will facilitate the success of Hispanics and other low income students in STEM areas.

### 1.2 Rationale for Challenge-Based Instruction

The activity described herein involves the development and implementation of Challenge-Based Instruction (CBI) in selected key courses, in particular, Statics and Dynamics. This activity has two foci, student retention and the student's development of adaptive expertise.

**Student Retention**

Research points to a need to see the relevance of studies to the real world[1] as one of four key reasons for minority-STEM students' decision to drop-out or transfer out of STEM undergraduate fields of study. The need to relate their studies to the real world results because minority students lack an equitable number of career influencers and role models within their families and familiar networks. Thus, when minority students select STEM fields of study, they experience an immediate need to confirm the relevance and compatibility of their studies and seek real world connections to their classroom learning experiences - connections that they do not find in the traditional classroom[1]. CBI focuses on student retention by directly addressing students' need to see Relevance of Studies to the Real World.

**Student Adaptive Expertise**

STEM professionals need not only a solid understanding of the fundamental principles and knowledge in their discipline, but they also need to be able to adapt as opportunities and applications as these fields evolve. Achieving this type of practical adaptability is not trivial. Often, people can develop advanced technical expertise in a field independent of an ability to adapt and innovate when presented with a novel problem to solve. The concept of Adaptive Expertise (AE) can help describe this ability. Hatano and Inagaki[2] distinguish between routine and adaptive expertise. Routine experts are technically proficient in their established domains of knowledge and application. They apply their well-developed knowledge base appropriately and efficiently to solve core problems in the domain. However, when they face a novel problem, they tend to misapply technical principles, analysis procedures, and outcome interpretations in their attempts to reach a solution[2-4]. In other words, they fail to adapt their expertise in a new context. Adaptive experts share the core technical proficiency of routine experts. Further, they are flexible in developing appropriate responses and solutions in novel situations. For example, they tend to review multiple perspectives when considering the solutions to new problems, and view their knowledge base as dynamic[2,3,5,6].

Schwartz, Bransford, and Sears[7] have proposed that there are two essential and complementary dimensions of AE: innovation and efficiency. Efficiency covers the taxonomic understanding of the field; innovation involves the ability to perform in novel situations. They have hypothesized that these two dimensions co-evolve in what they have called the optimal adaptability corridor (OAC): instruction that develops innovation and efficiency together will lead students to progress further along a trajectory toward AE than instruction that teaches for either efficiency or innovation first. This hypothesis has been validated in studies in CBI Biotransport classrooms[8]. However, in STEM disciplines the conventional approach has been to teach for efficiency first. Only after students have mastered certain content are they given opportunities to develop innovation in novel real-world settings during their final senior year courses. This approach has some downsides. First, studies have shown that one reason students leave STEM programs in the first few years is that they found too few opportunities to engage in creative activities that relate to the real world[9]. Other studies have found that focusing primarily on efficiency in early courses can suppress attempts at innovation in later educational experiences[10] and traditional methods can decrease students' innovative performance[11]. In contrast, instruction based on realistic challenges implemented with opportunities to attempt difficult problems independently and receive resources and lectures to help in the learning process, increases both students' innovation and efficiency[11].

## 2. Challenge-Based Instruction

Challenge-based instruction is a form of problem-based learning which indicates that for a learning environment to be effective, it must possess four common dimensions: a focus on the knowledge, learner, assessment and community[12]. In this way, CBI incorporates important cognitive and affective elements recommended for retaining underrepresented students[12, 13].

The approach in this study is directly based on the HPL inspired VaNTH model in which CBI is implemented in the form of a slightly modified STAR Legacy Cycle[14]. This cycle "is an exemplar of an inductive approach to teaching and learning"[15] and contains a directed sequence of steps that immerses the learner in the four dimensions of the HPL effective learning environment and provides a framework for CBI and the design of associated learning activities[16]. The cycle is illustrated in figure 1 and it is described next.


**Figure 1. Legacy Cycle**

## 2.1 Legacy Cycle (LC)

The legacy cycle consists of the process followed to solve challenges that are designed to motivate and engage students in learning activities. In the LC, the following steps are performed and repeated:

**Look Ahead**

The learning task and desired knowledge outcomes are described here. This step also allows for pre-assessment and serves as a benchmark for self-assessment in the Reflect Back step.

**Challenge 1 (shown in Figure 1)**

The first challenge is a lower difficulty level problem dealing with the topic. The student is provided with information needed to understand the challenge. The steps shown below represent the remainder of the cycle, which prepares the students to complete the challenge. Note that formative instructional events can and probably should occur in each step of the cycle. The following LC steps are to motivate and engage the students:

- <u>Generate ideas:</u> Students are asked to generate a list of issues and answers that they think are relevant to the challenge; to share ideas with fellow students; and to appreciate which ideas are "new" and to revise their list. ***Learner and community centered***.
- <u>Multiple perspectives:</u> The student is asked to elicit ideas and approaches concerning this challenge from "experts." ***Community and knowledge centered***.

- Research and revise: Reference materials to help the student reach the goals of exploring the challenge and to revise their original ideas are introduced here. ***Knowledge and learner centered***.
- Test your mettle: Summative instructional events are now presented. ***Knowledge and learner centered***.
- Go public: This is a high stakes motivating component introduced to motivate the student to do well. ***Learner and community centered***.

**Challenge 2…N**

The following progressively more ambitious challenges enable the student to increasingly deepen their knowledge of the topic being explored. Repeat the complete legacy cycle for each challenge.

**Reflect Back**

This gives student the opportunity for self-assessment**. *Learner centered***.

**Leaving Legacies**

The student is asked to provide solutions and insights for learning to the next cohort of students, as well as to the instructor(s). ***Community centered***.

The legacy cycle contains steps or activities that appeal to different learning styles[15] and most of those activities align themselves nicely with key phases of the engineering design process[17].

Therefore, a challenge begins with an open-ended problem followed by generating ideas and questions about the challenge. Then, students encounter multiple perspectives on the issue and have the opportunity to revise their initial ideas in light of new information from lectures, handouts, and other sources. In the final phases of CBI, students test their developing understanding of the concepts targeted by the challenge before going public with a final solution or response to the challenge. As students go over these steps, the facets of knowledge-, learner-, community-, and assessment-centeredness come into play.

CBI is *knowledge-centered* in its use of authentic engineering problems as the source of challenge material. A sense of *community* is established when faculty establish a personal connection with students while also emphasizing the need for student collaboration and communication with external resources as a means to solving the challenges.

Like mentoring, these collaborative learning strategies have positive results including improved academic performance and communication skills, increased student satisfaction with their learning experience and self-esteem, and improved retention[18]. However, unlike mentoring, CBI uses open-ended tasks to establish content competence and personal engagement in learning. Thus, CBI is uniquely *learner-centered* because it treats students' *questions* as a source of issues to investigate.

In turn, CBI's dual attention to students' questions (defined here as their potential for innovation) and emerging content competence (defined here as efficiency) means that CBI is *assessment-centered*, focusing on knowing what students know from both a formative and summative perspective.

## 2.2 Effectiveness of Challenge-Based Instruction

Much of VaNTH research focused on gains seen by LC CBI over traditional lectures in individual courses, or components of courses. Numerous other studies have also shown varying levels of effectiveness of this and other types of inductive teaching[15]. The assessment of the cumulative effect of inductive teaching and learning has been more a compilation of isolated effects rather than the assessment of a tightly coordinated sequence of interventions. Even so, “the collective evidence favoring the inductive approach over traditional deductive pedagogy is conclusive[15].”

VaNTH studies specifically demonstrated student learning improvement within the Biomedical Engineering student populations of its core institutions (Vanderbilt-Northwestern-Texas-Harvard/MIT). In one common course, taught as a technical elective in the ME departments at UT-Austin and at UTPA and solely comprised of VaNTH CBI learning modules, individual student gains were on average greater at UTPA than at UT-Austin[19]. This is most notable and irrefutable for the multiple choice overall course pre- and post-test results. In this case, UTPA class pre-test mean of correct answers was less than the UT Austin class pre-test mean; however, the UTPA post-test mean was greater than the UT Austin post-test mean. The significance of this difference in learning is illustrated by an individual differences effect size, with UT Austin as the control group, of 1.10. The effect size is a statistical measure, closely related to Student’s T-test, and an effect size of 1.10 indicates a 78% probability that a student from UTPA, experimental group, will learn more than a student from UT Austin, control group. The results of this assessment indicate that there is reason to believe that the CBI approach will improve student learning within the ME department at UTPA and served as a prime motivator for the CBI curriculum reform effort of which this work is a component.

Hence to address the issues of retention and development of student adaptive expertise, CBI is being introduced into the STEM curricula at UTPA, and in particular in Statics and Dynamics courses in this article, to enhance student learning by providing them with opportunities to see the relevance of studies to the real world and to develop adaptive expertise. Moreover, to produce a systemic change aimed at improving student learning approach and strategy, the Legacy Cycle is introduced early and often as guiding principle and as a self-recognized tool for lifelong learning; which should be done in a cost effective manner since this style of instruction typically has a high overhead in terms of both time and effort[20].

### 2.3 Curriculum Development Process

In general, the LC CBI modules developed at UTPA are designed according to a five-task “backwards design” process fostered by VaNTH and based on Wiggins and McTighe’s *Understanding by Design*[21]. The planning phase is composed of the first three tasks of Defining Objectives / Outcomes, Creating a Model of Knowledge, and Determining Evidence. The implementation phase is composed of tasks four and five, Selecting / Developing Materials, and Selecting / Providing Delivery. As stated in the VaNTH “Workshop on Designing Effective Instruction” (2009) manual these tasks involve the following activities. Defining Objectives involves identifying the objectives, identifying sub-objectives, identifying potential difficulties in accomplishing those objectives, and identifying real-world applications of the objectives. Creating a Model of Knowledge involves indentifying concepts and skills involved and how they relate to one another (i.e., creating a concept map), prioritizing the concepts and skills into the categories of Enduring Understanding, Important to Know and Do, and Worth Being Familiar With. Determining Evidence involves reviewing the objectives to determine acceptable evidence and planning the assessments to be used (e.g., Formative assessments for the LC Test Your Mettle step, and Summative assessments for the LC Go Public step). In light of the adopted LC approach, Selecting / Developing Materials involves designing effective real-world challenges (LC Challenge Question) to engage the students with the desired content and then selecting / developing learning materials to help the students master the objectives (e.g., lecture, simulation, video, experiment, etc. for use in the LC Multiple Perspectives and Research and Revise steps). Finally, Selecting / Providing Delivery involves determining how these materials should be delivered (e.g., listening to a live lecture, observing a simulation, reading an assigned text, viewing a video, etc.). In the following, an overview (and some of the materials) of the Legacy Cycle are presented as example challenges in both Statics and Dynamics.

## 3. Statics Challenge Example

This section describes a challenge that is being implemented in the Statics course during the Spring 2010 semester.

### 3.1 Look Ahead and Reflect Back

**Goals**

- To understand the basics of vectors and their use in solving problems in Statics
- Identify forces in a system and represent them in a FBD
- Apply equilibrium conditions in 2D and 3D to a concurrent force system

**Objectives**

- Find position vectors
- Calculate unit vectors
- Resolve vectors into Cartesian components
- Use the dot product to find angles between vectors
- Resolve vectors into components parallel and perpendicular to a line
- Draw FBDs
- Apply equilibrium conditions to a concurrent force system

### 3.2 Challenge Statement

The instructor make student teams to work together throughout the challenge. To present the challenge, the instructor introduces the following fictional story in Figure 2. It is recommended that the challenge be presented at the end of the class period prior to covering forces and vectors. The idea for this challenge was taken from a design problem in the textbook by Plesha et al.[22].

**Statics Challenge: Portable communication tower and cable support system.**

Due to weather conditions, a major communication tower in the Rio Grande Valley has failed and needs repair. As a result, the Texas Department of Information Resources (DIR) has launched a project that includes the design of a new portable communication tower to replace the main one while it is repaired.

The emergency tower consists of a fixed pole of height **6 m** supported by three cables having maximum cable force allowed of **30 kN.**

As an engineer, your challenge is to design a cable support system for this portable communication tower.

Figure 2. Challenge for Statics: Vectors and Forces

Figure 3 shows a sketch of the general situation for the portable communication tower and the cable support system.

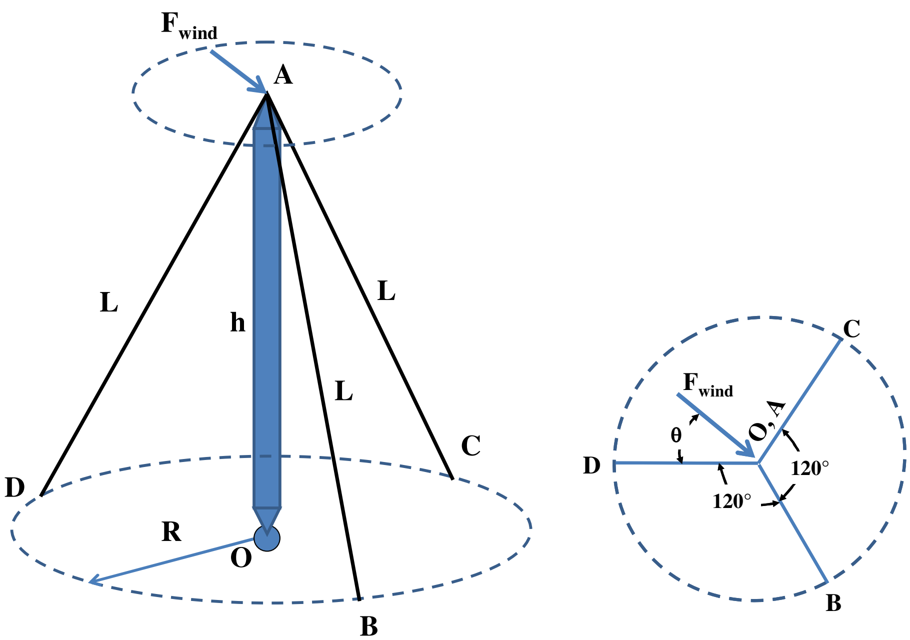



Figure 3. Portable communication tower

The plan to implement this challenge the first time is to extend it for about four weeks of the Statics course while concepts about 2D and 3D vectors and statics of particles are being studied. However, most challenge activities are performed by students outside of the classroom as teamwork homeworks. Statics is taught in three weekly 50-minute lectures for 15 weeks in the regular Spring and Fall semesters. The following steps and timeline are being planned for this Statics challenge:

- Pre-test and challenge handout and assignment of homework 1. This takes about 20 minutes of class time and the authors of this paper are preparing randomized questions with randomized answers for online implementation of the pre-test and post-test.
- Homework 1 consists of studying the challenge, brainstorming and generating ideas and questions; students are requested to submit this homework online through the Blackboard software platform. This takes about 1 week to be submitted by students and be graded by the instructor.
- Homework 2 consists of making free body diagram, finding unit vectors, representing forces in Cartesian form and determining and symbolically solving the equilibrium equations to obtain expressions for the cable forces as function of other parameters. This activity takes about one and a half week to be completed and graded. So far, the challenge has required about 3 weeks.
- Next, homework 3 consists of using Calculus or a graphical iterative way to determine the critical operating conditions of the support cables. As part of this homework, students

need to submit a report with all the results and a solution to the challenge. This takes about one more week to be completed.

- A post-test is performed during about 15 minutes of class time the same day that homework 3 is due.

In summary, this Statics challenge is taking approximately 40 minutes of class time and the rest is being done by the students through teamwork homeworks. This first challenge covers about 25% of the material studied in the Statics course. Three more challenges have been prepared for Statics, two about rigid bodies and one about trusses and frames. The following sections describe this challenge in more detail.

### 3.3 Pre-test

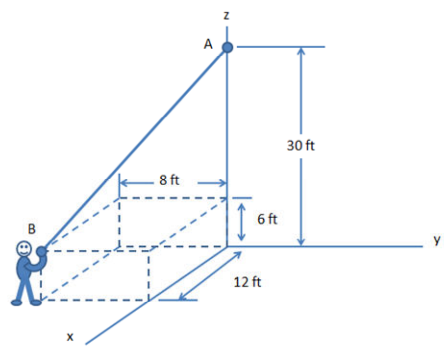
An important assessment tool is the pre-test which has to be given to the students before they start working on the challenge. The pre-test is a measure of the knowledge students have about the concepts targeted by the challenge before they do any work related to such challenge. It is recommended to include questions related to every concept and to put them in different contexts in order to estimate the adaptive expertise skills students develop during the challenge. Figure 4 present example questions included in the pretest and post-test. Notice that since the pre-test is performed before handing out the challenge, the "I don't know" option in the multiple choice questions was included to determine whether or not the students have previously been exposed to the concepts being evaluated. This option is also used in the post-test to make a correlation between learning level and student effort during the challenge activities.

### 3.4 Generate Ideas

Homework #1. The instructor assigns the "Generate Ideas" task requesting the student to write down ideas in clear complete sentences about the understanding of the challenge, the information they think should be required for the challenge and the steps that might be required to determine a solution. Answer the following:

**a.** How can you model this support system?
**b.** What factors affect cable loads?
**c.** In terms of design, how can you reduce cable loads to prevent failure?
**d.** Write down a list of questions you might have about the challenge.

For questions 8 – 11 refer to the figure shown below.




A man shown in the figure pulls on the cord with a force of 70 lb.

1) Determine the position vector **r** along the length of the cord going from point A towards point B.
   a. $r_{AB}$ ={–12**i** – 8**j** + 24**k**} ft
   b. $r_{AB}$ ={12**i** – 8**j** – 24**k**} ft
   c. $r_{AB}$ ={0**i** + 0**j** + 30**k**} ft
   d. $r_{AB}$ ={12**i** – 8**j** + 6**k**} ft
   e. I do not know
2) The magnitude of $r_{AB}$ which represents the length of cord AB is:
   a. 6.633 ft
   b. 784 ft
   c. 44 ft
   d. 28 ft
   e. I do not know
3) Determine the unit vector that defines the orientation and sense position $\mathbf{r}_{AB}$**,** and the force $\mathbf{F}_{AB}$**,** going from point A to point B.
   a. $u_{AB}$ = 0.429**i** – 0.286**j** – 0.857**k**
   b. $u_{AB}$ = 0.429**i** + 0.286**j** + 0.857**k**
   c. $u_{AB}$ = –0.429**i** – 0.286**j** + 0.857**k**
   d. $u_{AB}$ = 0.273**i** – 0.182**j** + 0.545**k**
   e. I do not know
4) If the force due to the rope acting at point A is 70 lb, its Cartesian vector form is:
   a. $F_{AB}$=(30**i** – 20**j** – 60**k**) lb
   b. $F_{AB}$=(30**i** + 20**j** + 60**k)** lb
   c. $F_{AB}$=(– 30**i** – 20**j** + 60**k**) lb
   d. $F_{AB}$=(19.11**i** – 12.74**j** + 38.15**k**) lb
   e. I do not know

Figure 4. Example questions included on the pre-and post-test

### 3.5 Multiple Perspectives

The instructor may present a short introductory lecture about antennas, transmitters and telecommunication towers. The Internet is a good source of multiple perspectives for the challenges. However, the instructor needs to find several good examples of such multiple perspectives to engage students in the challenge; for instance, studying support systems for wind turbines, trucks' towing structure, hanging weight attached to cables, a flying balloon held by ropes, and other similar situations.

- **a.** The support system can be modeled as a concurrent force system.
- **b.** The external force F can be due to wind, storm, hurricane, etc.
- **c.** The wind force can be modeled as a force F from any direction in the horizontal plane.
- **d.** Should think about the orientation of the horizontal wind force. Which orientation(s) leads to the most severe cable loads?
- **e.** Also think about how cables loads are affected with different values of R given an external force F.
- **f.** Compare large versus small values of R and determine what are better.

**3.6 Research and Revise**

In this part of the challenge, the instructor proceeds to present traditional lectures to explain concepts, work with examples, and implement classroom activities. The following should be presented to the students in this phase:

- **a.** Position vectors
- **b.** Unit vectors
- **c.** Resolving vectors into Cartesian components
- **d.** Using dot product to find the angle between two vectors or the projection of one vector onto another
- **e.** Drawing a free-body diagram for an object modeled as a particle (an object with mass but negligible shape/size – henceforth referred to simply as a particle).
- **f.** Solving particle equilibrium problems using the equations of equilibrium

Homework #2. FBDs and Equilibrium Equations

Establish your assumptions and do the following:

- **a.** Draw complete and clear free body diagrams of what you think are important components or points of the system.
- **b.** Work in a symbolic general way with unknown parameters. For example, use R for the radius, h for the tower height, L for cable length, and θ for the orientation of $F_{wind}$ throughout this homework #2. In homework #3, you will need to find these values and the critical value of θ that produces the maximum force in a specific cable.
- **c.** Write the equilibrium equations.
- **d.** Clearly express the magnitude of forces in cables AC and AD, ($\vec{F}_{AC}$ and $\vec{F}_{AD}$), as a function of R, L, $F_{wind}$, and θ.
- **e.** From the equations in part d), do the magnitude of the forces $\vec{F}_{AC}$ and $\vec{F}_{AD}$ increase or decrease by increasing the radius R?
- **f.** Make a list of questions you might have at this point of the challenge and attend your Professor's office hours if help is needed.

The instructor also provides the following guidelines to start narrowing down the challenge to specific tasks on which the students need to focus their efforts:

- **a.** All base supports are on a horizontal surface.
- **b.** Supports B, C, and D will each be located at the same radial distance R from the base of the tower (point O) such that BOC = BOD = COD = 120°.
- **c.** Neglect the weight of the cables in your calculations.

**d.** Assume cables are not pre-tensioned. Hence, initially with $F_{wind} = 0$, all three cables carry no load.

**e.** If you suspect that a cable is in compression, assume it supports no load. For example, when force $F_{wind}$ lies in sector CAD, the force in cable AB is 0 N.

**f.** Notice that the length of the cables is $L=\sqrt{h^2+R^2}$ .

<u>Homework #3.</u> In this part of the challenge students need to use either an iterative approach or use differential and integral calculus to determine at which value of an independent variable a function has maximum values.

**a.** Which orientation(s) θ of horizontal wind force leads to the most severe cable loads? How did you determine these orientation(s)? Take one of the following two approaches:
*Iterative approach:*

- Use h = 6 meters and $F_{wind}$= 20 kN. Choose two different reasonable values of R. Work keeping one of those values of R constant and find the forces in the cables for different values of θ; determine at what angle θ the tension in the cable(s) is maximum. You need to plot each force $F_{AC}$ and $F_{AD}$ versus the angle for θ from 0° to 120° (consider that your plotting software might work in radians). Do the same for the other value of R. Is the critical angle θ where the tension in the cable(s) is maximum the same for the two different values of R?
- After that, if the critical angle found in a) is the same for any value of R, work with such critical angle, and find the minimum radius R required if the maximum $F_{wind}$ is estimated to be 20 kN during a hurricane and the forces in the cables must not exceed 30 kN.

*Differential and Integral Calculus approach:*

- Write the tension in the cables as a function of the angle θ and radius R and while assuming R constant, determine the critical value of θ that makes the tension of the cable(s) maximum. Use what you learned in Calculus to determine the maximum of a function.
- After that, if the critical angle found in a) is the same for any value of R, work with such critical angle, and find the minimum radius R required if the maximum $F_{wind}$ is estimated to be 20 kN during a hurricane and the forces in the cables must not exceed 30 kN.

**b.** Challenge Report. Prepare a report of your challenge work and present a solution to the challenge and your conclusions. Write clear complete sentences in your conclusions.

- Free body diagram and equilibrium equations
- Equations of the magnitudes of the forces $\vec{F}_{AC}$ and $\vec{F}_{AD}$ as functions of other parameters.
- Plots of magnitude of forces $\vec{F}_{AC}$ and $\vec{F}_{AD}$ versus the angle θ.
- What is the minimum radius R needed for the support system, explain?
- Conclusions.

### 3.7 Test Your Mettle

**a.** Formative assessment

- Lecture and class work

- Questions during office hours
- Traditional homeworks

**b.** Summative Assessment
- Report with solution to the challenge
- Post-test

**3.8 Go Public**

**a.** Students submit several homeworks to solve the challenge in multiple sequential steps.
**b.** Students prepare an engineering report summarizing design and supporting analyses.
**c.** Post-test. Another important assessment tool is the post-test which has to be given to the students after they turn in their challenge report. The post-test should be similar or identical to the pre-test for comparison purposes.

## 4. Dynamics CBI Timeline and Challenge Example

The dynamics course is being taught in three 50-minute class periods each week for fifteen weeks. The basic schedule for the course is shown below in Table 1. There are ten challenges ranging from 2 to 4 class periods in duration, overall course pre-test and post-test (the dynamics concept inventory is used for both), four exam review days, and four exams. Although most of challenge solutions require both kinematic and kinetic content, the challenges have been designed to follow the standard learning objective sequence of particle kinematics, particle kinetics, rigid-body kinematics, and rigid-body kinetics to assist in transferability of the materials.

Table 1: Dynamics CBI Timeline

| Challenge | Number of class periods | Learning Objectives & Assessment |
|---|---|---|
| ***Overall Course Pre-Test*** | 1 | ***Dynamics Concept Inventory*** |
| **1: Terminal Velocity** | 3 | Basic Kinematic Relationships |
| **2: Traffic Signal Timing** | 3 | Piecewise Continuous Motion |
| **3: Incoming** | 3 | Ballistics and Mixed Coordinates |
| Review | 1 | |
| ***Exam #1*** | 1 | ***Particle Kinematics*** |
| **4: The Big Slip** | 3 | Ballistics and Particle Work-Energy |
| **5: Roller Coaster Design** | 2 | Particle W-E and Newton's $2^{nd}$ Law |
| **6: Road Design** | 4 | Particle NSL and Friction |
| Review | 1 | |
| ***Exam #2*** | 1 | ***Particle Kinetics*** |
| **7: Artillery Practice** | 4 | Rigid-Body Kinematics |
| **8: Appliance Moving** | 3 | RB Newton-Euler and Pulleys |
| Review | 1 | |
| ***Exam #3*** | 1 | ***RB Kinematics and Linear Motion N-E*** |
| **9: Drag Racing** | 4 | RB General Motion: N-E and W-E |
| **10: Ship Stabilization** | 4 | RB Momentum |
| Wrap-up | 1 | |
| ***Overall Course Post-Test*** | 1 | ***Dynamics Course Inventory*** |
| ***Final / Exam 4*** | | ***RB Kinetics*** |

Generally, the particle dynamics challenges are covered in three days with the rigid-body challenges requiring four days. The specific daily breakdown for the relatively short example challenge *Terminal Velocity* is given below in Table 2. The challenge itself and its learning objectives are given at the end of day one. The students then bring their generated ideas concerning what is important to know or do to solve the challenge to class on day two. Then, during the class, their ideas are reviewed and other perspectives are given about what is important (sometimes these are just the instructor's thoughts; but, often this will include computer software simulations, using Mathcad and Working Model 2D extensively). This usually focuses on conceptual understanding as opposed to numerical solution of particular problems. During the third class, examples related to the challenge are presented, some of which are "test you mettle" homework problems. Then, at the beginning of the next class, a student group (usually a group of three students) gives a quick presentation of their solution to the challenge. They also hand in their "test your mettle" problems (which are standard textbook problems) and a write-up of their challenge solution. Hyperlinks are used within the schedule to guide students to the desired content. The challenge itself along with its learning objectives is viewed first. The links in the learning objectives column take students to lecture style text documents describing the derivation of the three differential and six integral equations relating position, velocity, acceleration, and time, and helpful integration hints to assist the students answer the challenge exercises. The multiple perspectives link typically takes the student to computer simulations and/or tutorial movies. The Research & Revise link takes them to solved example problems, and the Test Your Mettle link takes them to the Challenge related exercises (standard homework problems).

Table 2. MECE 2304 Dynamics – Spring 2010 - Course Schedule

| | Day | Date | Topics | Learning Objectives* |
|---|---|---|---|---|
| 1 | Wed | Jan 20 | What (do you think) is Dynamics? (5 mins)<br>Introduction to Challenge-Based Instruction (10 mins)<br>Informed Consent<br>**Challenge 1: Terminal Velocity** Look Ahead | Basic Kinematic Relationships |
| 2 | Fri | Jan 22 | Course Pre-Test (25 mins)<br>Generate Ideas and Multiple Perspectives | |
| 3 | Mon | Jan 25 | Research & Revise and Test Your Mettle | **Integrals Help** |
| 4 | Wed | Jan 27 | Go Public<br>Intro. to **Challenge 2: Stop Light Timing** | Piecewise Continuous Motion |

The remainder of this section further describes the content of the Terminal Velocity challenge.

### 4.1 Look Ahead and Reflect Back

**Goals**

- To be able to derive and apply the basic kinematic relationships between position, velocity, acceleration, and time
- Recognize that shape, surface texture, and Reynolds number have an effect on drag

**Objectives**

- Draw FBD's
- Apply Newton's Second Law in 2D to a "particle"
- Obtain integrals of single variable, non-polynomial functions

**4.2 Challenge Statement**

Which can fall faster, a human or a peregrine falcon?

**4.3 Challenge Pre-test**

The challenge pre-test should contain knowledge-based, skills-based, and transfer type questions. A pre-test was implemented at the beginning of the course to cover most concepts studied in the course; therefore, pre-tests for the individual challenges are not given this Spring 2010 semester in Dynamics.

**4.4 Generate Ideas**

For homework (or as an in-class activity to be handed in) have the students answer the following:

- What measure can be used to answer the challenge question?
- What factors affect this measure?
- Where can you go to find information concerning these factors?
- Write down a list of questions you might have about the challenge.

**4.5 Mul**tiple **Perspectives**

The Internet is often a good source of multiple perspectives for the challenge. A great video for this challenge is http://www.youtube.com/watch?v=1ukf2vntU44. After viewing such video, the instructor can ask the following corollary questions:

**a.** Do you believe Mark's claim that he fell at a terminal velocity of 300mph?
**b.** How long would it take him and how far would he fall to reach 90% of this speed?

A second, short in-class, Generate Ideas activity is appropriate here. Using two different WM2D simulations; one for falling with variable drag coefficients, and another for shooting bullets straight up in the air. These simulations can be found at http://mece.utpa.edu/~rafree/DynamicsSp10/C1%20Terminal%20Velocity/

**4.6 Research and Revise**

With respect to corollary question 4.5a), the instructor may now present a short introductory lecture about drag. Many websites are also suitable for discussion of drag (e.g., http://en.wikipedia.org/wiki/Drag(physics) and http://en.wikipedia.org/wiki/Dragcoefficient). With respect to corollary question 4.5b), an instructor led discussion takes place leading to the derivation of the six distinct integral relationships between position, velocity, acceleration and time from the definitions of velocity and acceleration (e.g., http://mece.utpa.edu/~rafree/DynamicsSp10/C1%20Terminal%20Velocity/pg1-8_BKR.doc).

**4.7 Test Your Mettle**

Formative Assessment

A set of standard textbook homework questions concerning the relationships between position, velocity, acceleration, and time and/or straight forward questions involving known drag coefficients and concerning FBDs, terminal velocity, and the integration of Newton's 2nd Law could be given as homework. The following is a typical example homework problem.

Given an object of mass m = 80 kg, falling in a gravitational field, and acted on by a drag force $F_d = 2V^2$. Find: 1) The object's terminal velocity, and 2) how long it takes to get to 95% of that velocity. You may find the integral equations (1) and (2) useful.

$$\int \frac{1}{Av^2 - b} dv = \frac{1}{\sqrt{bA}} \operatorname{atanh}\left( A \frac{v}{\sqrt{bA}} \right) \tag{1}$$

$$\int \frac{v}{Av^2 - b} dv = \frac{1}{2A} \ln\left( Av^2 - b \right) \tag{2}$$

**4.8 Go Public**

Summative Assessment

- The students are to hand in a report with solution to the challenge and corollary questions. This could be simply a written report that is posted on the course web-site and/or accompanied by an in-class presentation. They also hand in the homework.
- Post-test. The post-test should be similar or identical to the pre-test for comparison purposes (not given this Spring 2010 semester for each individual challenge).

## 5. Conclusion

Currently there are four developed CBI challenge modules for Statics covering approximately 80% of the course content/learning objectives, and ten developed CBI modules for Dynamics completely covering the course content. Assessment of this activity is just beginning. The plan is to have assessed two sections of both control and CBI sections for each course in terms of pre- and post-tests by May 2011. Part of the assessment will include tracking the effect on pre-test results in courses that require Statics and Dynamics as pre-requisites. This will be reported on as the results become available. Even though implementation of the CBI approach and its formal assessment in Statics and Dynamics is just beginning, student engagement when first presenting an interesting challenge and then leading the student to discover the appropriate associated theory is unmistakably greater than when presenting the theory first and then asking questions answerable with that theory. And, although CBI has a high initial overhead, the challenge modules are readily transferable and as more faculty members begin to adopt this approach there will/can be a sharing of development overhead. Plus, it is a lot more fun for the instructor. Finally, while students are almost universally more engaged up front, it is sometimes difficult to maintain that level of enthusiasm because strict adherence to the LC CBI approach requires the student to think more than normal. In any event, the underlying goal of this approach is to teach students not just content knowledge but how to adapt that knowledge and acquire new knowledge to solve problems.

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