

## **Implementing a Challenge-Based Approach to Teaching Selected Courses in CS and Computational Sciences**

**Dr. Mahmoud K. Quweider, University of Texas - Rio Grande Valley**

M K Quweider is a Professor of Computer & Information Sciences at the U. of Texas at UTRGV. He received his Ph.D. in Engineering Science (Multimedia and Imaging Specialty) and B.S. In Electrical Engineering, M.S. in Applied Mathematics, M.S. in Engineering Science, and M.S. in Biomedical Engineering all from the University of Toledo, Ohio. He also holds a Bachelor of English and a Masters of Business Administration from the University of Texas at Brownsville. After graduation, he was employed at several corporations including Pixera, a digital multimedia processing company in Cupertino, CA, 3COM, a networking and communication company in Schaumburg, IL, and Mercantec, an E-Commerce company in Naperville, IL. He has more than 40 publications in the field, and has served as a reviewer/moderator for several scientific and educational journals and conferences. He joined UTB in the Spring of 2000. His areas of interest include Imaging, Visualization and Animation, Networking and Cyber Security, Web Design, Computer Graphics, and Linguistics.

**Prof. Fitratullah Khan, University of Texas - Rio Grande Valley**

Professor Fitratullah Khan has been teaching computer science courses since 1992. His areas of expertise are computer architecture, networking, database systems, computing platforms and languages. As the director of Infrastructure, Telecommunications, and Networking (ITNet), and later as the Chief Technology Officer, at UT Brownsville, he implemented state of the art networking using campus wide fiber ring with redundant links to facilities. He established diskless computer labs to provide uniform computing platform across campus, and modernized classrooms to make them congenial to online learning. He was the PI on NSF funded BCEIL (Beowulf-based Curriculum Enrichment Integrated Laboratory) grant and Co-PI on NSF funded MCALL (Multimedia based Computer Assisted Learning Lab) grant.

# Implementing a Challenge-based Approach to Teaching Selected Courses in CS and Computational Sciences

## Abstract

Challenge Based Instruction/learning (CBI) has been championed as an effective methodology to engage students in their own learning process, allowing them to deal with real-life problems and projects that need to be solved. As *The New Media* Consortium eloquently puts it, "[Challenge-based learning] calls for a new way of thinking about the role of the teacher, one in which he or she had to be comfortable as the students struggled and wrestled with a meaningful challenge, letting them choose their own path to understanding."

The approach is even more challenging to implement in the SMT (Science, Mathematics, and Technology) fields at minority-serving institutions requiring trained faculty.

This paper describes in detail our efforts to implement CBI in the Computer Science curriculum in general, and Computer Graphics (CG) and Software Engineering (SWE) in particular. The effort is part of an NSF grant awarded to UT Pan Am and UT Brownsville (both are now part of the newly merged university of UT Rio Grande Valley). The CG and SWE courses were selected because of the initial high enrollment but the low retention rate. The paper documents the efforts that have been made in specific areas of the newly implemented courses. These include:

1. The process of identifying course major module objectives and module sub-objectives, in particular, those that are relevant to CBI implementation.
2. Identifying expected difficulties: What are the difficulties that students face when taking the course?
3. Real-world context: Why is the course an important part of the CS curriculum, and where can one find its applications?
4. Knowledge model: What is the conceptual model for the course, including prerequisites, course dependencies, and course level? What concepts and techniques should be considered to enhance understanding of the material?
5. Assessment of learning: How does one change the traditional testing and assessment methods to make sure these include formative assessment (individual and group, in class and outside the class homework) as well as summative assessment?

Data analysis and conclusions from the pilot project have been made public to benefit other faculty in CS and other SMT fields nationwide.

## Keywords

Challenge Based Instruction/learning (CBI), Interdisciplinary Studies, Engineering, Computational Science, Computer Graphics, Software Engineering. SMT (Science, Mathematics, and Technology) fields at minority-serving institutions.

## Introduction

The advent of the 21<sup>st</sup> century with its technological advances has witnessed an explosion in the amount of information available to everyone through tools such as search engines, free encyclopedias, on-line databases, and multimedia content, just to mention a few. The changes in the way we acquire such information, juxtaposed with the way students are immersed in these technologies, have necessitated that we re-evaluate and take a closer look at the traditional instructional and curricular approaches we, faculty, use with our students. One of the possible approaches that has proven its effectiveness in many disciplines including STEM is Challenge Based Instructions (CBI) [1-6], which has been lauded for being student/learner centered, for being an active-learner based, and for being inquiry based. While the approach is relatively new, it presents a natural approach for STEM curricula which are usually complex, real-world, and multi-disciplinary.

In order to adopt a CBI approach in Computer Science (CS), one of the authors was elected to participate in a workshop, sponsored by two neighboring universities as part of an on-going grant on CBI, in order to become familiar with the process, to select the appropriate courses and to create the proper material. The attended workshop (and later follow-ups) presented a structured process, a framework, that provided a disciplined, systematic, and quantifiable approach for the development, operation, and assessment of the created curriculum modules. The lessons learned from the workshop were shared with the other two authors as well as the rest of the CS faculty.

## CBI Workshop Highlights

### Backwards Design Process



**Figure 1. Backwards Design**

The attended workshop was sponsored by the center of Excellence in STEM at The University of Texas Pan-AM as part of a grant funded by the US department of Defense. The 2-day workshop aimed at presenting hands-on experience on designing effective instruction. The first part of the workshop emphasized the 5-stage/task backwards design (modified framework from Wiggins & McTighe, *Understanding by Design*, 1999) used to guide the content modules for the courses that will use the CBI modules [6]. The model is shown in Figure 1. We were asked to keep in mind the following general objectives to emulate as we went through the 5-tasks planning stage:

- Promote conducting fundamental research on learning and instruction
- research issues and opportunities related to designing learning environments that produced competent engineers
- Infuse technology as an integral part of instruction

- Create sharable resources

Next, the details of the five tasks are presented, followed by introduction to the CG/SWE modules that were developed based on the model.

### Planning

The planning stages of the backwards design process include objectives, model of knowledge, and evidence.

### Backwards Design Process-Planning: Objectives

The goal of this task is to identify the goals of instruction, including major goals and specific sub goals:

- Major course objectives
- Course sub-objectives
- Potential difficulties
- Real-world contexts

### Backwards Design Process-Planning: Model of Knowledge

After identifying all the objectives, we next identify a model of knowledge that achieves these goals. This is usually given in the form of a concept mapping diagram. An example of such a map given in the workshop is shown in Figure 2.

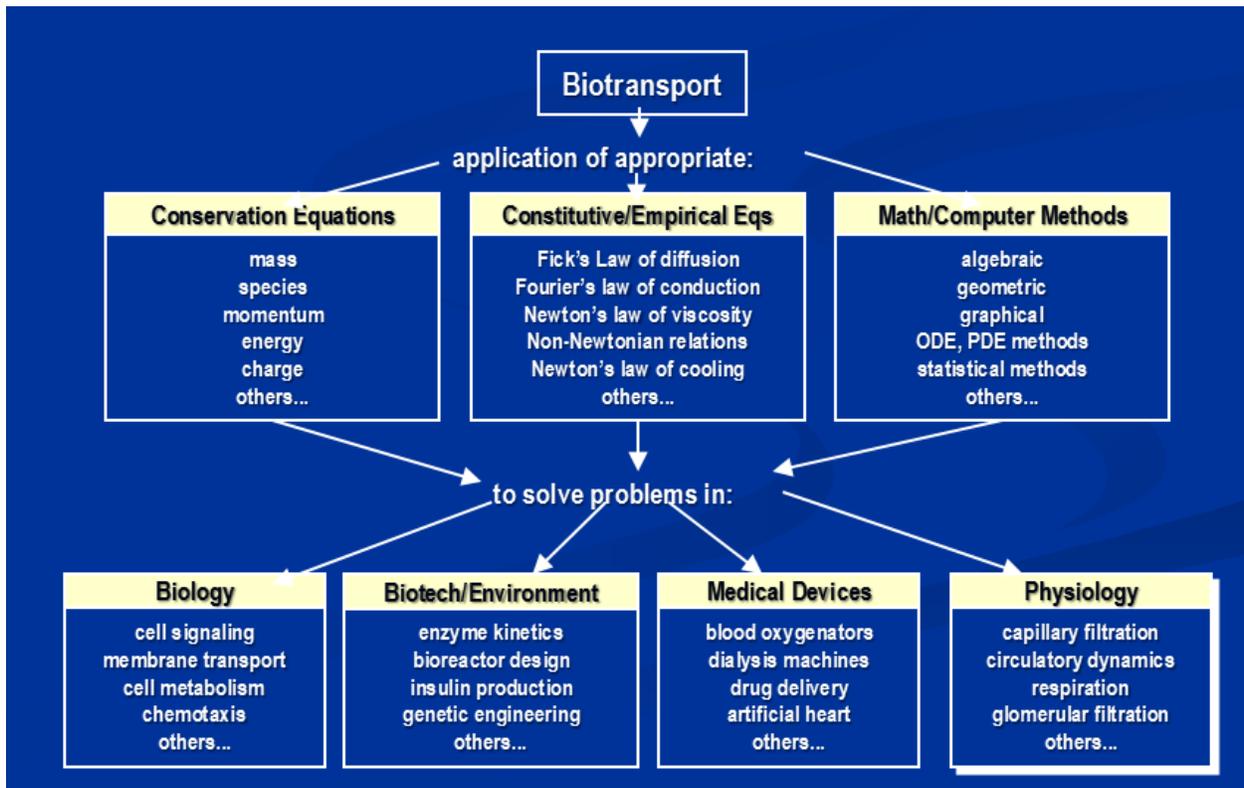


Figure 2. Concept Mapping (Adapted from workshop material)

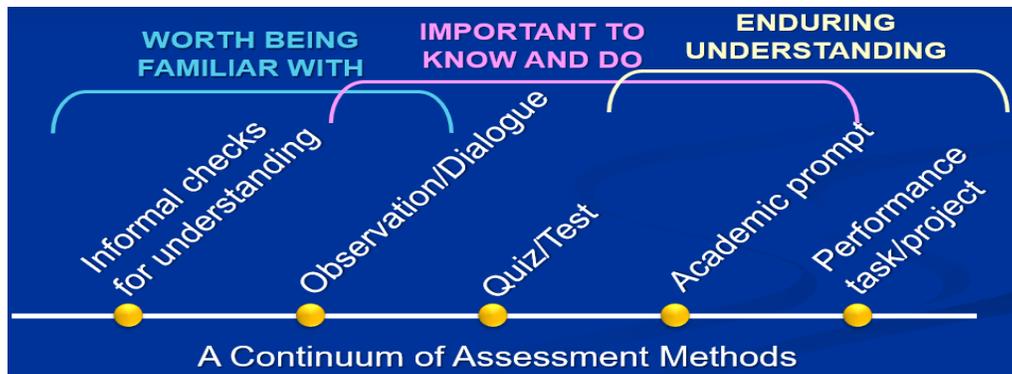
The goal of the concept map is to identify and prioritize the multi-disciplinary aspects of the challenge, the real and practical aspects of research and data collection (if any), and to see how they can be adapted to the current problem. The faculty are then asked to prioritize the concept mapping into the following categories:

- Enduring Understanding - concepts fundamental to achieving course objectives and to the domain in general
- Important to Know and Do - ideas and skills necessary for achieving objectives, but not necessarily requiring total mastery by the end of the course
- Worth Being Familiar with - things not critical to performing a desired course outcome, but students should be aware of their association with the course objectives

### Backwards Design Process-Planning: Evidence

Once the goals are written down (each with its category), we move towards Identifying the assessments for these goals (both formative and summative).

In this stage, the faculty is encouraged to think of the assessment as being on a continuum as shown in Figure 3, with the understanding that formative assessment is designed to “inform” both students and instructor how well they are doing. Its primary purpose is not to give a grade, but to see how much learning and understanding have occurred; and summative assessment is designed to “sum up” a final grade.



**Figure 3. Continuum of Assessment methods and their relationship to the goals. (Adapted from workshop material)**

The following table should be used as a guide when performing assessments. Assessment should reflect objectives with the following mapping in mind:

- **Worth Being Familiar with** → dialogue, observation, multiple choice
- **Important to know and do** → short answer, structured problem
- **Enduring understanding** → concepts synthesis & skills mastery

**Table 1. Basic Guide to Assessment. (Adapted from workshop material)**

<b>Informal Checks for Understanding</b>	<b>Observation/Dialogue</b>	<b>Quiz and Test Items</b>	<b>Academic Prompts - open-ended questions/problems</b>
<p><b>ORAL:</b></p> <ul style="list-style-type: none"> <li>- “Why do you say that?”</li> <li>- “How do you know?”</li> </ul>	<p><b>Observation:</b></p> <ul style="list-style-type: none"> <li>- the observer must have in mind the criteria that demonstrate knowledge and proficient</li> </ul>	<ul style="list-style-type: none"> <li>- Assess factual information/concepts/discriminate skill</li> <li>- Use selected-response or short-answer formats</li> <li>- Typically have a single, best answer (convergent)</li> <li>- Are easily scored</li> <li>- Are typically not known in advance (secure)</li> </ul>	<ul style="list-style-type: none"> <li>- Require constructed response under exam condition</li> <li>No single best answer or strategy (open)</li> <li>- Often ill-structured, requiring development of strategy</li> <li>- Involve analysis, synthesis, or evaluation</li> <li>- Require explanation/defense of answer/method given</li> <li>Require judgment-based scoring based on criteria</li> <li>- May or may not be known in advance</li> </ul>
<p><b>Written:</b></p> <ul style="list-style-type: none"> <li>- Single sentence summary</li> <li>- One minute paper</li> <li>- Muddiest Point</li> <li>- Plusses and Deltas</li> </ul>	<p><b>Dialogue:</b></p> <ul style="list-style-type: none"> <li>- the person assessing must be skilled in forming questions that reveal the other’s knowledge.</li> </ul>		

**Backwards Design Process-Implementation**

The implementation part of the backwards design process is focused on developing good challenge questions targeting knowledge to be learned to help identify the information sources. Based on the challenge selected, the appropriate learning activities to meet learning goals are then identified.

The following sections detail the different phases in the development, implementation, and assessment of CBI modules that were undertaken in the two CS courses at the undergraduate level.

### **CBI Curriculum Development**

The two initial courses selected for implementing the CBI approach were CG and SWE. The same developed module, called Projectile-based 2-D Games, was used for the two courses. To take the module in either course, students must have the prerequisites shown in Table 2. The prerequisites include basic Calculus and Physics courses, which are necessary to derive projectile based equations based on differential calculus and Newtonian motion equations.

<b>Table 2. STEM Requirements</b>		
<b>Prefix and Number</b>	<b>Required Courses</b>	<b>SCH</b>
MATH 2413	Calculus I	4
PHYS 2213	Physics I	3
PHYS 2214	Physics II	3
COSC 4330	Computer Graphics	3
COSC 4346	Software Engineering	3

### **CBI Students Statistics**

The student enrollment numbers for the two courses were as follows:

<b>Table 3. Students Statistics</b>		
<b>Course</b>	<b>Initial Enrollments</b>	<b>Dropped/Fail</b>
CG Computer Graphics	38	8
Software Engineering	26	2

### **CBI Challenge**

The students were given the following challenge:

**How many of you play basketball or shoot darts or play soccer. How does a basketball player control his/her shot? How does a dart shoot adjust his/her shot according to the target? What would the player do when the basket is too far? What would the player adjust if the hoop was too high or too low? How would a player adjust if the game was played outside with gusty winds? If a player shoots a dart and a basketball with the same velocity and angle, which one would go the farthest: the dart or the basketball?**

Students were then allowed to do a research and revise to derive the following relevant equations on their own.

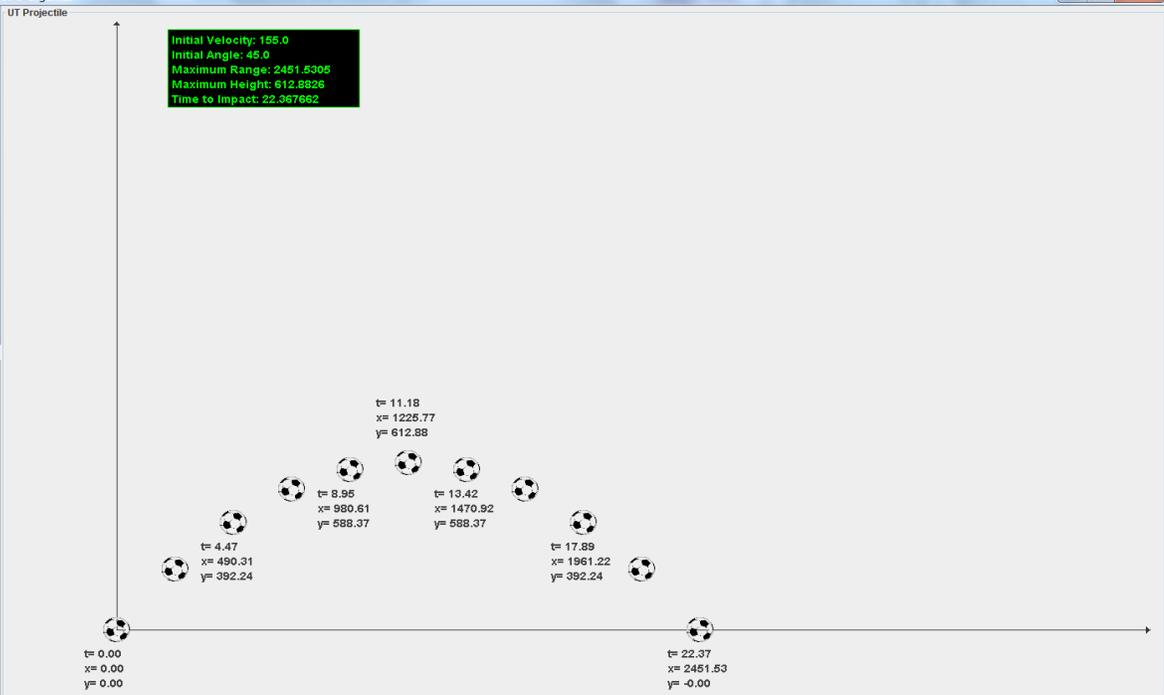
Distance Equations:	$x(t) = v_0 \cos(\theta)t$
with $(x_0=0, y_0=0)$	$y(t) = v_0 \sin(\theta)t - (gt^2)/2$
Velocity Equations:	$v_x(t) = v_0 \cos(\theta)$
	$v_y(t) = v_0 \sin(\theta) - gt$
	$v(t) = \sqrt{v_0^2 - 2gtv_0 \sin(\theta) + g^2 t^2}$
Maximum Height:	$H = (v_0^2 \sin^2(\theta)) / (2g)$
Occurs when $v_y(t) = 0$ (i.e. $y'(t) = 0$ )	
Time to Impact:	$T = (2v_0 \sin(\theta)) / g$
Range:	$R = x(t)_{t=T} = v_0 \cos(\theta)T$

**Figure 4. Projectile equations developed by the students through research/revise**

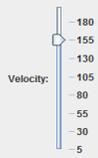
These equations were then used to create different projectiles through a simple interface as shown below in Figure 5. To make it more fun, students had a choice between a soccer ball and an angry bird as their projectile object.

Fire the AngryBird-Data Trace

Fire the AngryBird-No Trace

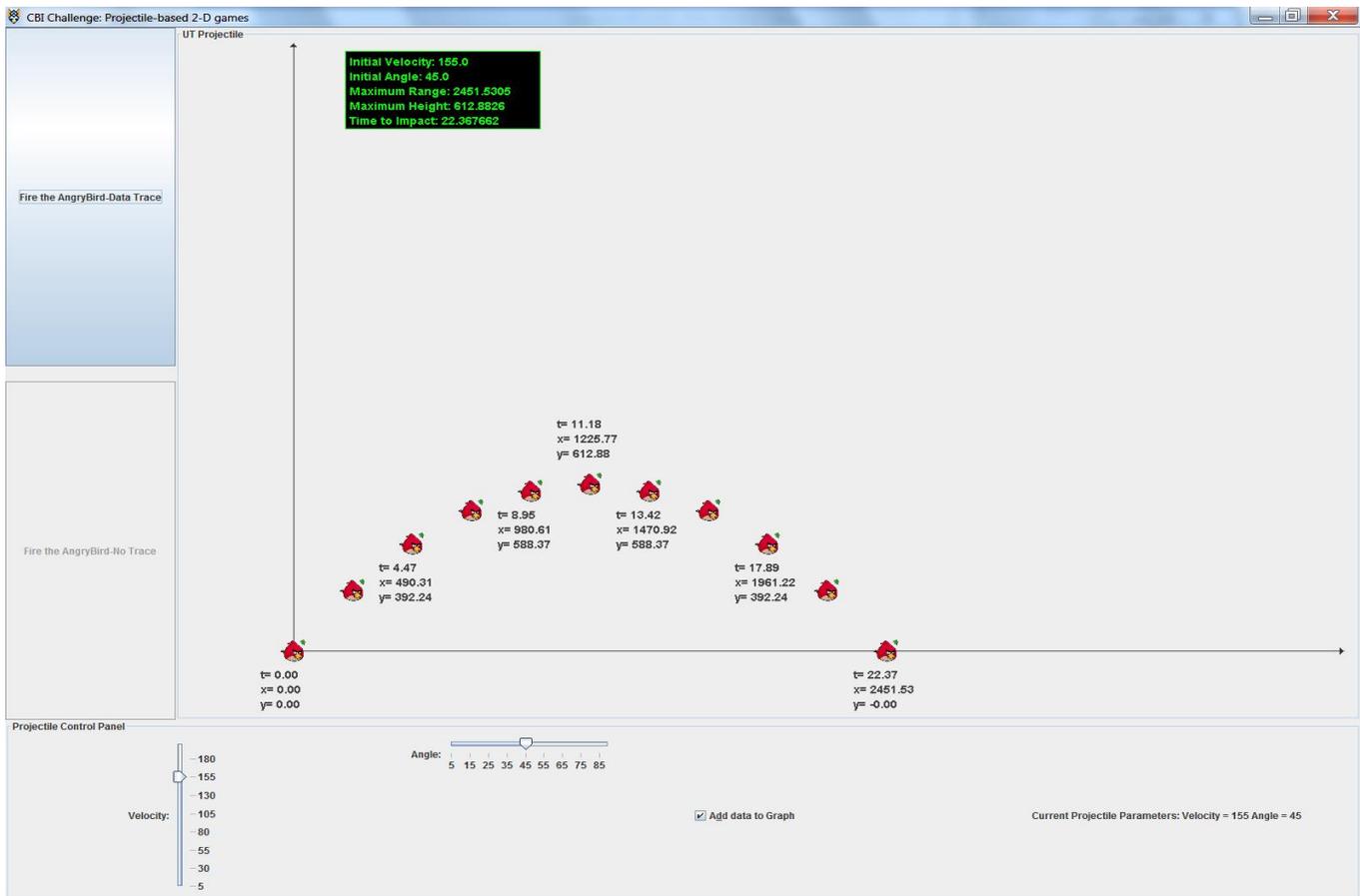


Projectile Control Panel



Add data to Graph

Current Projectile Parameters: Velocity = 155 Angle = 45



**Figure 5.**  
**CBI Challenge Projectile-based 2-D Interface**  
**a) with Soccer Ball b) with Angry Bird**

## CBI Analysis

### Faculty Feedback

Due to resource limitations, one professor was assigned to attend the workshop and to implement the CBI module. The professor has expansive educational and industrial experience in Computer Graphics and Software Engineering, as well as Image Processing and Multi-media. The professor introduced the module in the two courses and asked the students to form groups of 4-5 to start working on the challenge.

The professor noticed an immediate change in the students' attitude towards the course. The challenge was enthusiastically accepted by the students and each group went through four to ten iterations of the research and revise cycles. Some of the students reported using baseball and basketball practices to relate to the mathematical formulas they came across.

The assessment results for the course were very positive and students showed a higher rate of retention compared to previous offerings of the courses. For the CBI based course, the drop-out rate was around 16% compared to more than 25-30% in previous offerings of the course.

Some of the improvements were related to the students' interpersonal skills such as oral and verbal communications. Their enthusiasm and ability to describe the problem in terms of sports and gaming actions were really eye-catching. Many of the students were actually practicing sports techniques that have their origin in maximizing/minimizing the range of a projectile, but never had the chance to make the connection.

### **Student Feedback**

Many of the students in the course gave a positive feedback in the course evaluation. Few of the students complained about the lack of structure at the beginning and the lack of guidelines to pursue the challenge, which was by design to break away from the usual lecture/example routine. However, once they went through the first research and revise phase, they became more involved and were able to implement the challenge successfully, and more importantly independently.

During the course, and to determine how the students perceived their experience with the CBI modules, the faculty asked them to provide feedback by answering the following questions:

1. How do you feel about the CBI module?  
**More than 89% of the respondents said that they liked the new format. Some students wanted to use their own tools such as game engines (which was not allowed in the two courses). However, the use of the students preferred tools can be accommodated in other courses such as the Senior Project.**
2. What resources did you use during the research and revise phases?  
**Almost 100% of the respondents mentioned Google, YouTube and other Open courses from other universities. Interestingly, no one mentioned University databases!**
3. What knowledge from CS and other STEM areas did the challenge demand?  
**100% of the respondents mentioned Calculus I, II and Physics. Some students added College Algebra.**
4. Did the challenge help appreciate the role of other disciplines as they relate to CS?  
**100% of the respondents said YES. One student mentioned that he will pursue a double major of Mathematics and Computer Science. On the negative side, one student said "while the course is fun, I found out that it was not for me."**

### **Broader Impact**

The benefits gained from the CBI workshop were expanded to other courses by the engaged faculty. For example, the projectile module is now the nucleus of many modules that are used for teaching multi-threading in other courses such as Gaming and Software Engineering. The CBI methodology is also implemented in Software Engineering where a set of teams are assembled at

the beginning of the course and each team is required to complete a real-life project from beginning to end, going through the five phases of the software process: Requirements, Design, Implementation, Testing, and Maintenance.

Currently, one of the professors is trying CBI in one of the graduate courses he is teaching. The field of the course (Computer Vision) is very broad, and students take the course for different reasons. Rather than enforcing a specific project on all the students, students are allowed to select a project of interest and tackle it using the CBI methodology.

## **Conclusions and Future Work**

CBI seems to be a natural choice for a STEM related field such as Computer Science due to its complex and inter-disciplinary nature. The adoption of CBI modules in targeted courses was enthusiastically welcomed by many students. Although our results do not prove the superiority of the CBI compared to other traditional methodologies, the CBI approach did offer our students the framework and skills to bridge the gap between traditionally disparate sciences. The course evaluations filled by students, and the reflective summary by the involved faculty, show many positive improvements in attitude, independence, attendance, learning engagements, immersion, and mood. We also measured significant improvements in programming and problem solving, especially as it related to mathematics and physics, as well as in decision making.

Some of the skills that CBI targeted were interpersonal skills, oral and verbal communications, and presentations.

## **Acknowledgment:**

Part of this work was conducted while attending the workshop sponsored by the Center of Excellence in STEM at UT Pan Am. Some of the diagrams and figures are based on the workshop presentation given by Dr. Harris Alene, and Dr. Harris Thomas during their visit in 2012. We greatly appreciate their work and thank them for providing the material for the workshop.

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## APPENDIX A

### DETAILED DEVELOPMENT

#### MODULE: PROJECTILE-BASED 2-D GAMES

##### I. Backwards Design

###### Course Title and Description

###### Computer Graphics Course Description

The student is familiarized with structured graphical objects. The algorithms for transforming, clipping, and projecting objects are put into practice through several projects. Hidden line/surface removal, shading/lighting models, and the problem of aliasing are studied.

Prerequisite: Algorithm analysis.

###### Major Module Objectives

Students who successfully complete this module should demonstrate the following learning outcomes out of the course outcomes:

- a. Provide an understanding of how a computer draws the fundamental graphics primitives - lines and filled polygons in both 2-D and 3-D.
- b. Use the facilities provided by a standard API to express basic transformations such as scaling, rotation, and translation.
- c. Implement simple procedures that perform transformation and clipping operations on a simple 2-dimensional image.
- d. Discuss the 3-dimensional coordinate system and the changes required to extend 2D transformation operations to handle transformations in 3D.
- e. Explain the concept and applications of each of these techniques.
- f. Describe efficient algorithms to compute radiosity and explain the tradeoffs of accuracy and algorithmic performance.
- g. Explain image-based rendering techniques, light fields, and associated topics.

###### Module Sub-Objectives

- a. Apply knowledge of computer graphics gained in a game/simulation application using OpenGL or Java 2-D.
- b. Implement a simple 2-D projectile-based game.
- c. Develop a simulation/visualization 3-D scene that is rendered with lighting, texture mapping, and a variety of 3-D objects.

###### Difficulties

Students may have difficulty:

- Adapting Physics and Calculus concepts (of distance, velocity and acceleration) into the digital domain.
- Solving projectile, free fall, and collision detection problems.

- Extend the projectile objects into multiple and simultaneous objects that update in real time.

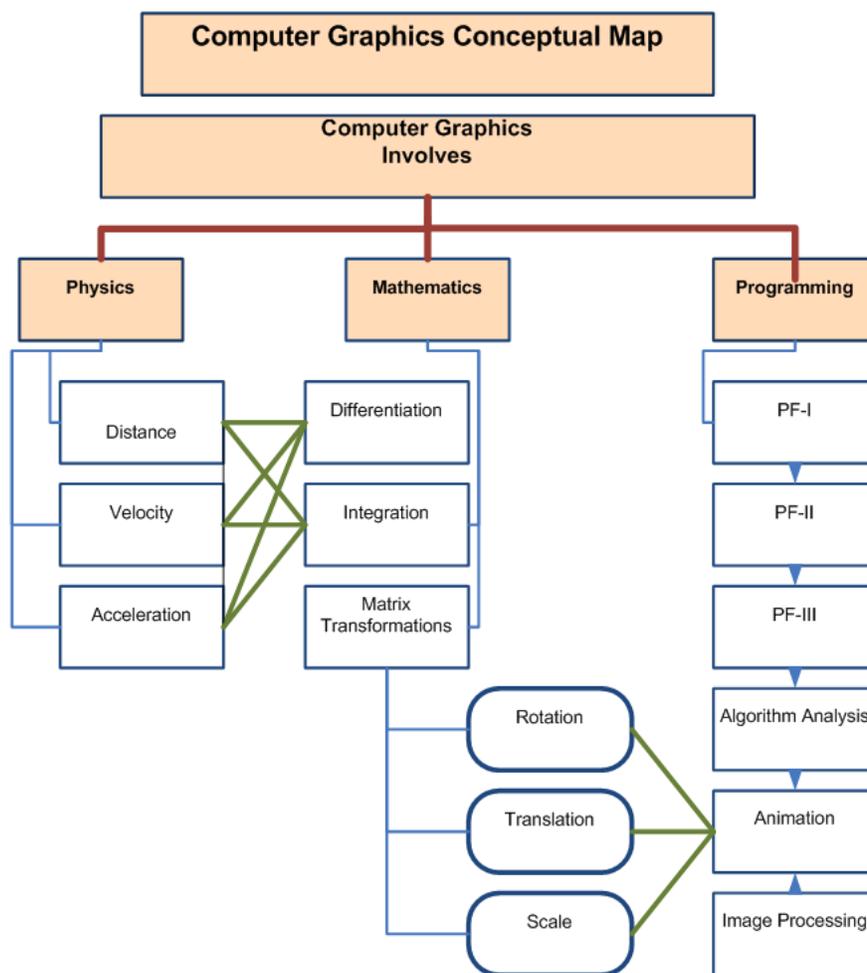
### Real-World Contexts

There are many ways that students can use this material in the real-world, such as:

- Playing and/or developing a 2-D game.
- Develop a simulation or visualization based on 2-D Physics and Calculus concepts (such as fountain weather phenomenon, Monte Carlo simulation).

## II. Model of Knowledge

### 1. Conceptual Model



### 2. Content Priorities

#### 2.1. Enduring Understanding

- Distance, velocity, and acceleration are fundamentally related through differentiation and integration and initial values.

- Transformation are used to generate any model view in Computer Graphics
- Calculating projectile motion in x and y directions through vector analysis
- One type of animation involves constant updating of objects in scenes through timers (time-driven event through fixed size steps)

## 2.2. Important to Do and Know

- Free-fall as special case of projectiles
- Effect of Time step (smallest unit in model used)

## 2.3. Worth Being Familiar with

- Effects of wind and other factors for realistic animations

## 3. Assessment of Learning

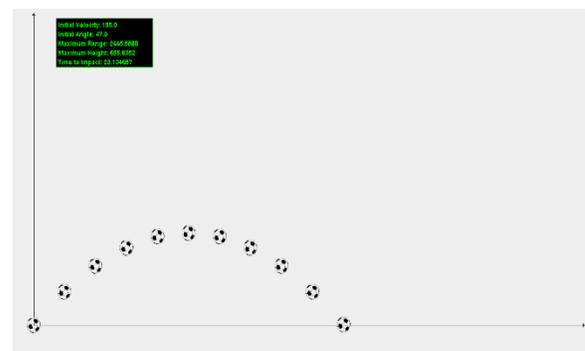
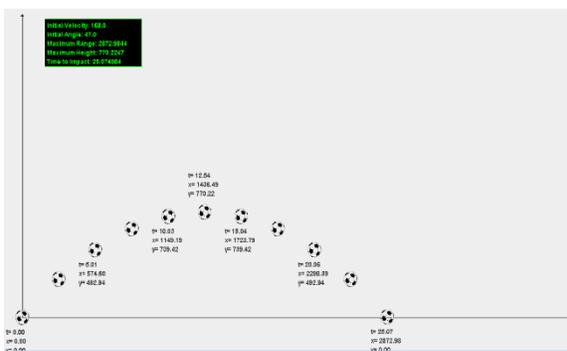
### 3.1. Formative Assessment

#### 3.1.1. In Class (groups)

- Conduct free-fall experiments with different objects
- Throw objects with different angles and velocities
- Draw 2-D projections from 3-D scenes to see a model view vs. world view.

#### 3.1.2. Homework (individual)

- Use basic differentiation and initial conditions to calculate the distance, velocity, maximum height, range, and time to impact of an object thrown at a specific speed and angle, ignoring the effects of air resistance.
- Create a basic OOP program (in console mode—no animation yet) to implement the above solution.



### 3.2. Summative Assessment

- Compare two objects thrown at different velocities and angles.
- Implement a simple 2-D game that will shoot an arrow toward a target. The game should create objects at random distances.

### III. Legacy Cycle

The following activities relate to the legacy cycle and its enhanced 4Es as shown in Figure 4.



Figure 4. Legacy Cycle contrasted with the five E's.  
(Adapted from workshop material)

#### 1. OBJECTIVE

By the next class period, students will be able to:

- Load an image file representing an object to be released (an arrow, an angry bird, cannon ball).
- Create a projectile object that computes distance and velocity at different instances of time.
- Create an animation using a timer and use threads.

#### 2. THE CHALLENGE

Students will be asked: How many of you play basketball or shoot darts or play soccer. How does a basketball player control his/her shot? How does a dart shoot adjust his/her shot according to the target? What would the player do when the basketball is too far? What would the player adjust if the hoop was too higher or too low? How would the player adjust if the game was played outside with gusty winds? If a player shoots a dart and a basketball with the same velocity and angle, which one would go the farthest: the dart or the basketball?

### 3. GENERATE IDEAS

- a. Students should discuss what variables would be used in a program to compute the distance and the velocity at certain intervals of time? They should come to consensus whether mass is a factor or not, and under what circumstances?
- b. Students should discuss vector analysis in coming up with the proper equations for the projectile.
- c. Students should discuss how to update projectile objects through timers.

### 4. MULTIPLE PERSPECTIVES

- a. By this point, students should have generated a list of relevant variables for the 2-D projectile game.
- b. Students will bring a dart game and/or mini-hoops game to practice in class.
- c. Students will visit an on-line gaming website and play a projectile-based game
- d. Students will watch parts of basketball game, focusing on shooting from different locations.
- e. Invite a Physics professor to review Newtonian Physics and projectiles

### 5. RESEARCH & REVISE

- a. Student will have access to lecture notes covering Mathematics and Physics for gaming.
- b. Demonstrations from previous projects will be given.
- c. By this point, students should have collected all relevant variables that will be used for the game.
- d. Students will be grouped together and each group will create an OOP console-mode program for the projectile.
- e. Each group will present both a simulation as well as written calculations for a projectile object with an initial velocity and initial angle.
- f. After all groups have presented, students will work individually to incorporate the animation aspects of the project.

### 6. TEST YOUR METTLE

Students will take quizzes on projectiles and on animation. Students in the same group will grade each other's quiz and teach each other until everyone is comfortable with the mathematics of projectiles. A similar set of quizzes can be taken again afterwards, with possible repetition on individual basis.

### 7. Go PUBLIC

Each student will program a final project, a 2-D projectile-based game, using either OpenGL or Java 2-D. Students will, however, have an option as to which game they would like to implement. The game will control velocity and angle through a human-computer interface such as mouse, keyboard, touch screen, or joystick. The final projects will be showcased in the course website.

## IV. Pre-Lesson Quiz

- a. You just downloaded the popular Angry Birds game. As you play the game (on your phone, or in the lab, or on your computer), try to figure out how the game is

implemented. What are the variables you change as you push the bird up or down, left or right?

**V. Test Your Mettle Quiz**

- a. You shoot a dart at a speed of 10 m/s with an angle of 50. What is the time for impact.
- b. What is the maximum height and what is the maximum range for the dart in question a.
- c. You shoot a dart at a speed of 10 m/s with an angle of 45. What is the time for impact.
- d. What is the maximum height and what is the maximum range for the dart in question c.
- e. How would you extend the projectile object to represent a fleet of objects (such as spaceships or water drops of a fountain). Hint: Arrays; Data Structures.