

# A Heat Conduction iPhone and iPad App for Engineering Education

Jason Keith, Gerald Nelson, Abby Thompson,  
Read Sprabery, and John Gazzini

Mississippi State University

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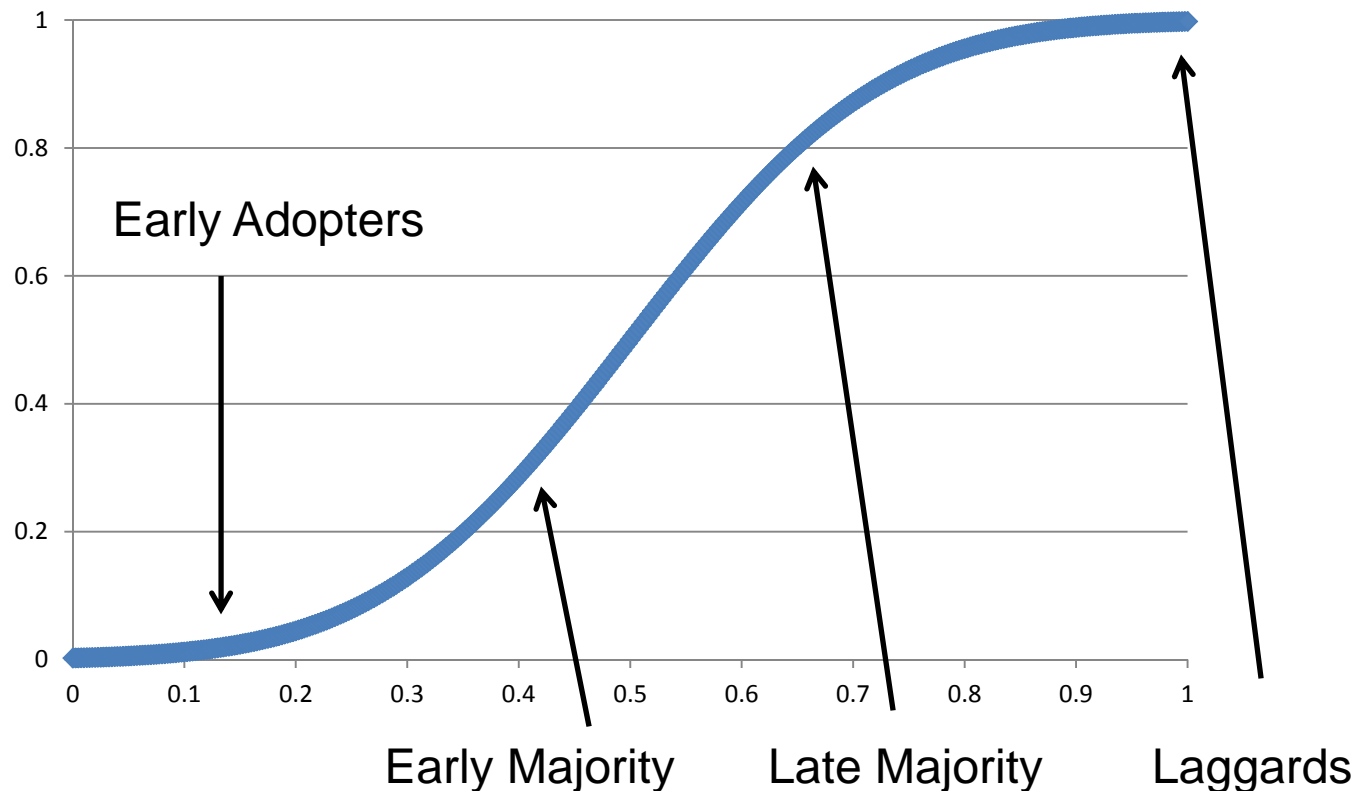


# Background

- Students learn best by doing
- More and more important to use active learning as student learning styles have shifted over the past generations
- Today's students are visual learners
- Students are always on their phones
- Education apps can have positive learning benefits

# Introduction

- Use of consumer products follows the diffusion of innovation



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# Diffusion of Innovation Concepts

- Recycling
- Portable CD players
- Sustainability
- Smart Phones
  - Opportunity to develop apps to improve student understanding / learning

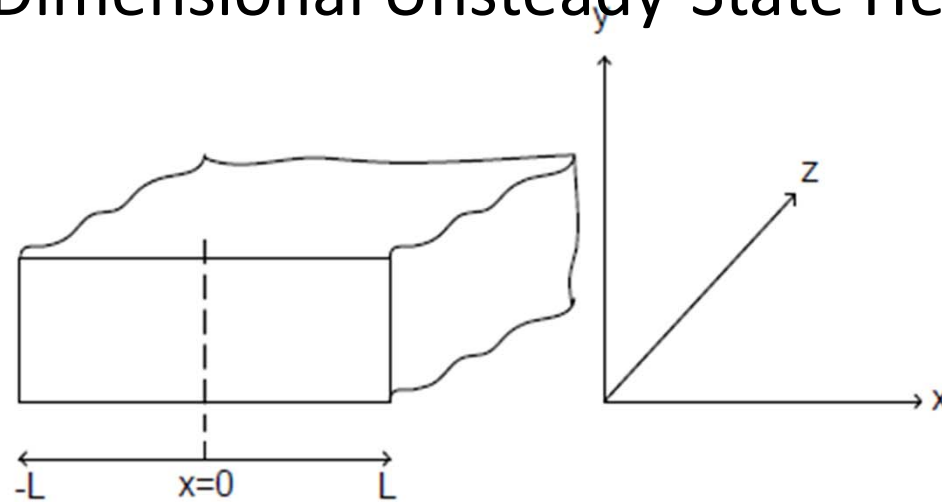
# Mathematical Background

- Fundamentals

- Heat Conduction  $q_c = -k \frac{\partial T}{\partial x}$

- Convection  $q_h = h(T - T_f)$

- One Dimensional Unsteady-State Heat Conduction



# Mathematical Background

- Governing Equation  $\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2}$
- **Boundary Conditions:** No flux at  $x = 0$   $\frac{\partial T}{\partial x} = 0$
- Conduction = Convection at  $x = L$   $-k \frac{\partial T}{\partial x} = h(T - T_f)$
- **Initial Condition:** at  $t = 0$ ,  $T = T_0$

# Solution

- Infinite series

$$T = T_f + (T_0 - T_f) \sum_{n=1}^{\infty} A_n \cos\left(\frac{\lambda_n x}{L}\right) \exp\left(-\frac{\lambda_n^2 kt}{\rho C_p L^2}\right)$$

- Recursion relation for  $\lambda$ , with  $Bi = hL/k$

$$\lambda_n \tan \lambda_n = Bi$$

- $A_n$  depends on initial condition, such that:

$$A_n = \frac{\frac{\sin \lambda_n}{\lambda_n}}{\frac{1}{2} + \frac{\sin 2\lambda_n}{4\lambda_n}}$$

# App Development - CS

- “*Heat Transfer for Students*” – **Free download!**
- Target platform iOS and Apple devices
- MacBook Pro for all algorithm development and testing as well as user interface design and optimization
- iPhone 4S running iOS 5.1 as a test bed
- Software coded in XCode 4.2 (Free)
- Development in Objective C
- 120 lines of code



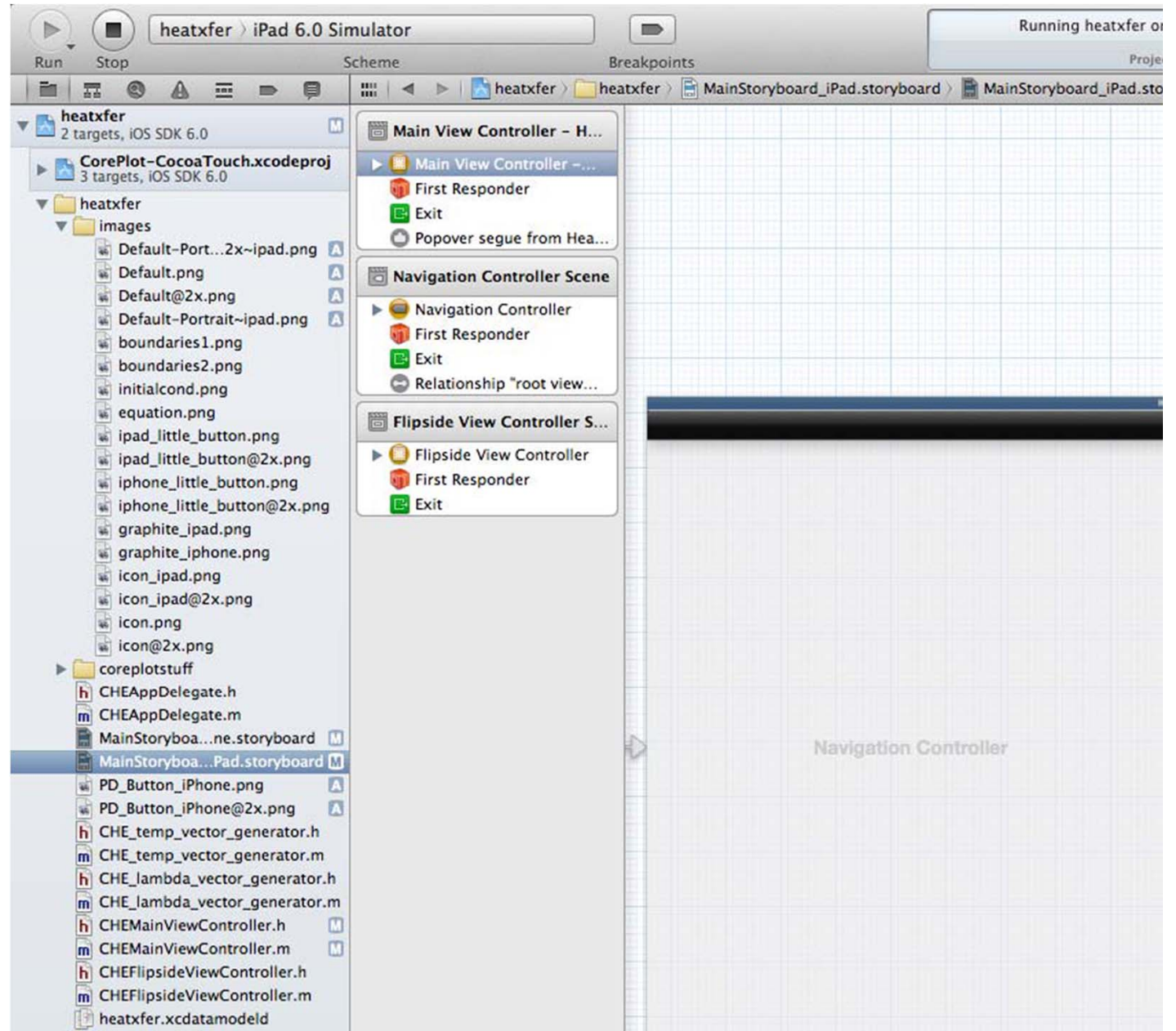
# App Development - CHE

- Core Plot (Free) graphing library to develop plots of temperature vs. position at different times
- Plot displays 201 points
  - Invoke symmetry about x-axis
- Value of  $\lambda$  is needed for program
  - Computations are very fast on the iPhone!
  - Transcendental equation solved for first 50 roots
- Animation at 10 frames / second

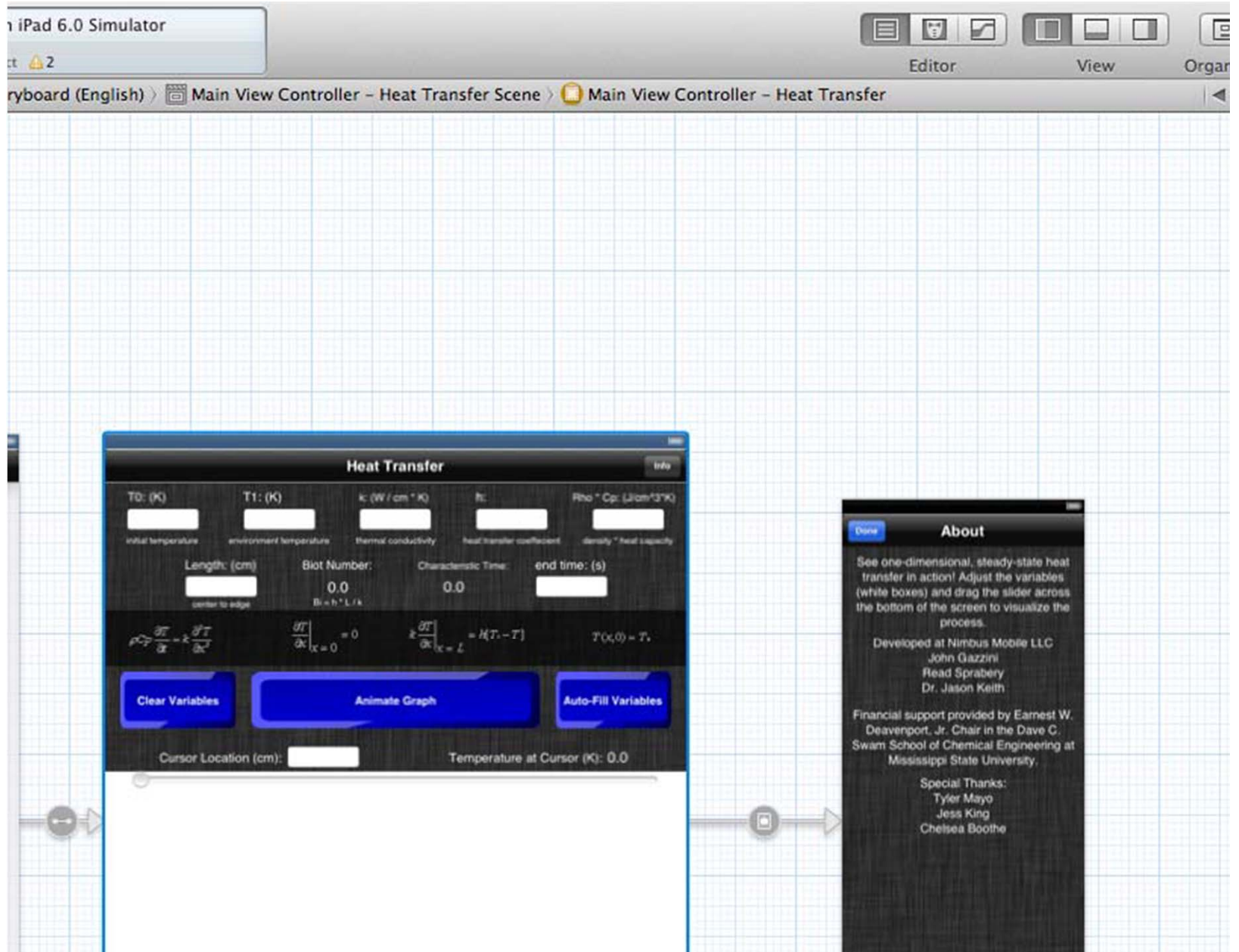
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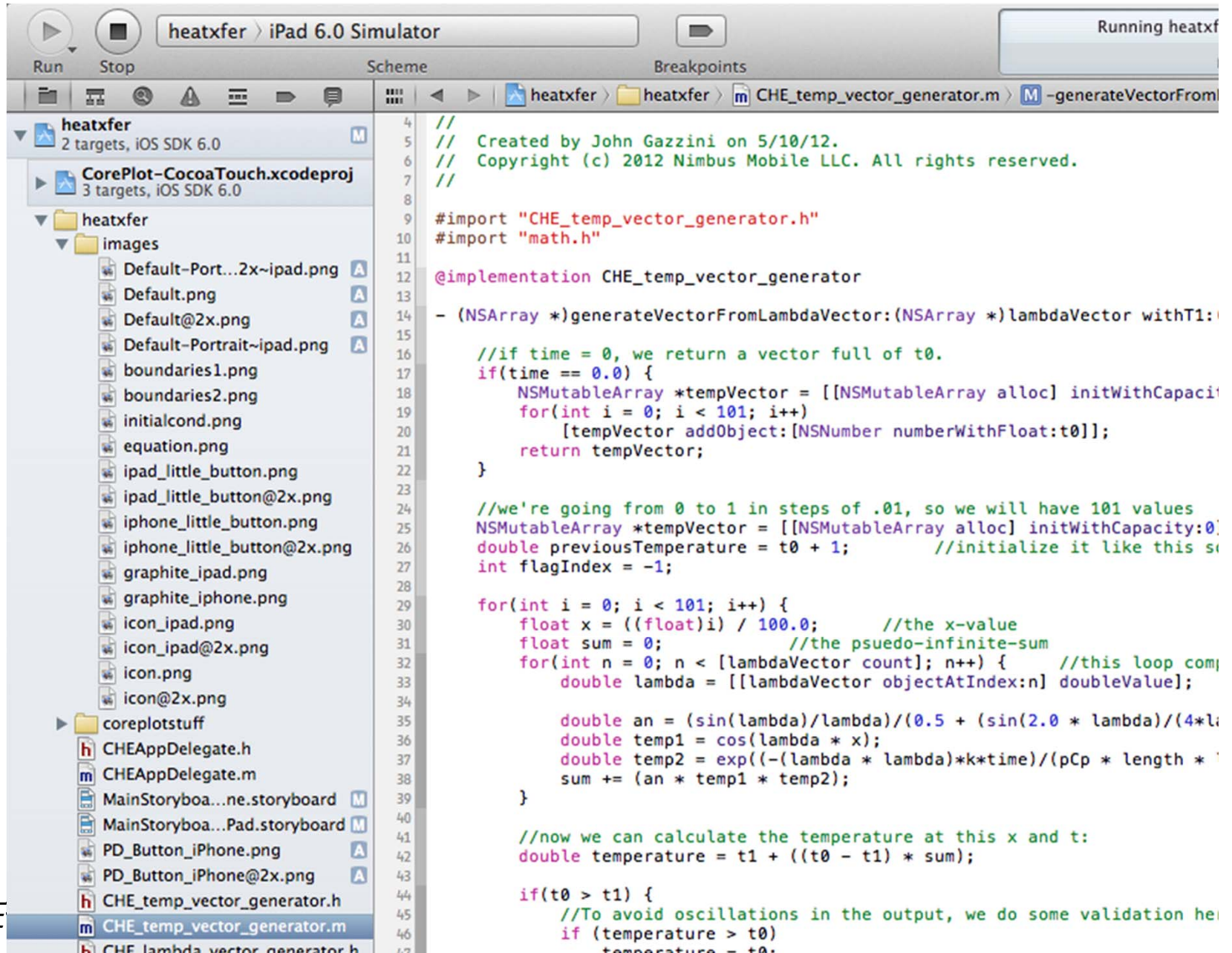
# App Development - Images



# App Development - Images

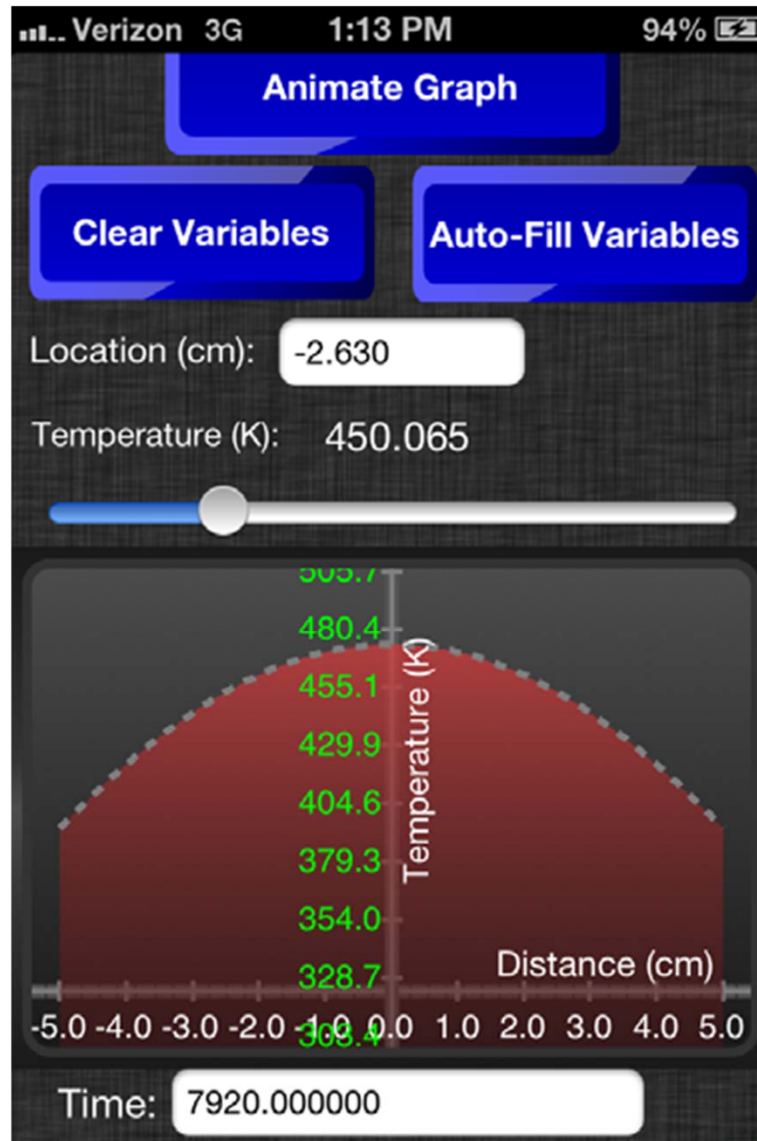
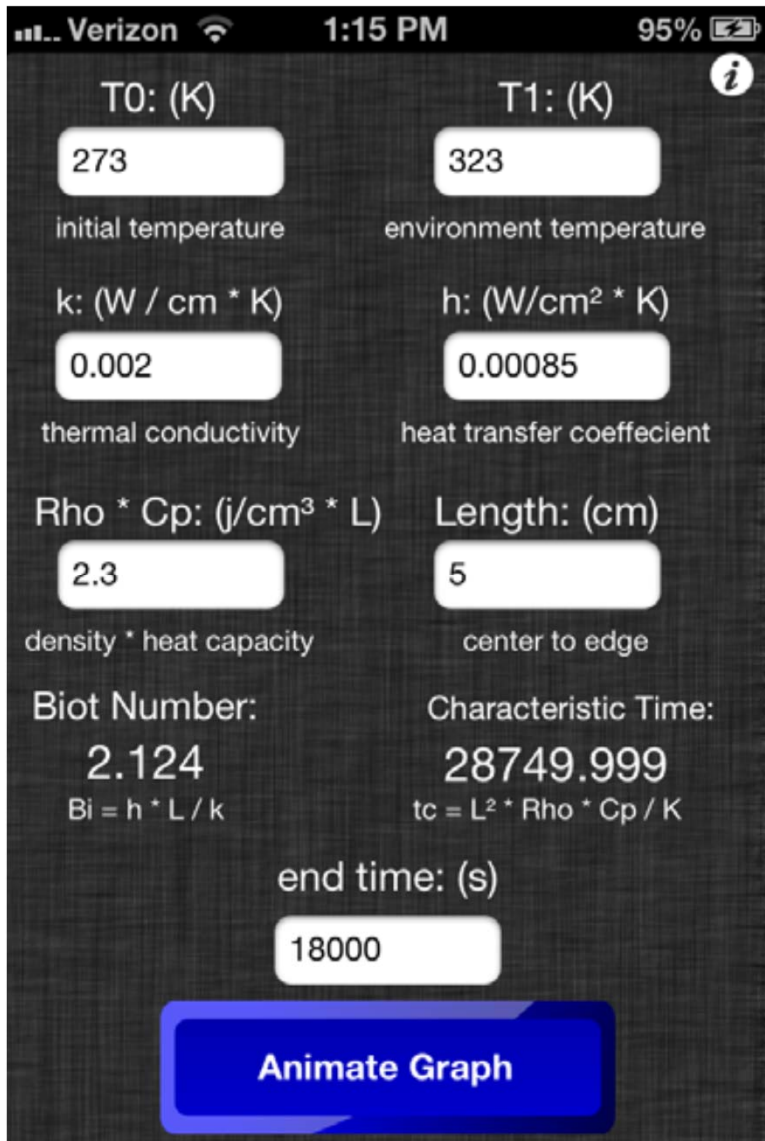


# App Development - Code



```
4 //
5 // Created by John Gazzini on 5/10/12.
6 // Copyright (c) 2012 Nimbus Mobile LLC. All rights reserved.
7 //
8
9 #import "CHE_temp_vector_generator.h"
10 #import "math.h"
11
12 @implementation CHE_temp_vector_generator
13
14 - (NSArray *)generateVectorFromLambdaVector:(NSArray *)lambdaVector withT1:
15
16 //if time = 0, we return a vector full of t0.
17 if(time == 0.0) {
18     NSMutableArray *tempVector = [[NSMutableArray alloc] initWithCapacity:101];
19     for(int i = 0; i < 101; i++)
20         [tempVector addObject:[NSNumber numberWithFloat:t0]];
21     return tempVector;
22 }
23
24 //we're going from 0 to 1 in steps of .01, so we will have 101 values
25 NSMutableArray *tempVector = [[NSMutableArray alloc] initWithCapacity:101];
26 double previousTemperature = t0 + 1; //initialize it like this so we can calculate the
27 int flagIndex = -1;
28
29 for(int i = 0; i < 101; i++) {
30     float x = ((float)i) / 100.0; //the x-value
31     float sum = 0; //the psuedo-infinite-sum
32     for(int n = 0; n < [lambdaVector count]; n++) { //this loop computes the sum
33         double lambda = [[lambdaVector objectAtIndex:n] doubleValue];
34
35         double an = (sin(lambda)/lambda)/(0.5 + (sin(2.0 * lambda)/(4*lambda)));
36         double temp1 = cos(lambda * x);
37         double temp2 = exp(-(lambda * lambda)*k*time)/(pCp * length * lambda);
38         sum += (an * temp1 * temp2);
39     }
40
41 //now we can calculate the temperature at this x and t:
42 double temperature = t1 + ((t0 - t1) * sum);
43
44 if(t0 > t1) {
45     //To avoid oscillations in the output, we do some validation here
46     if (temperature > t0)
47         temperature = t0;
```

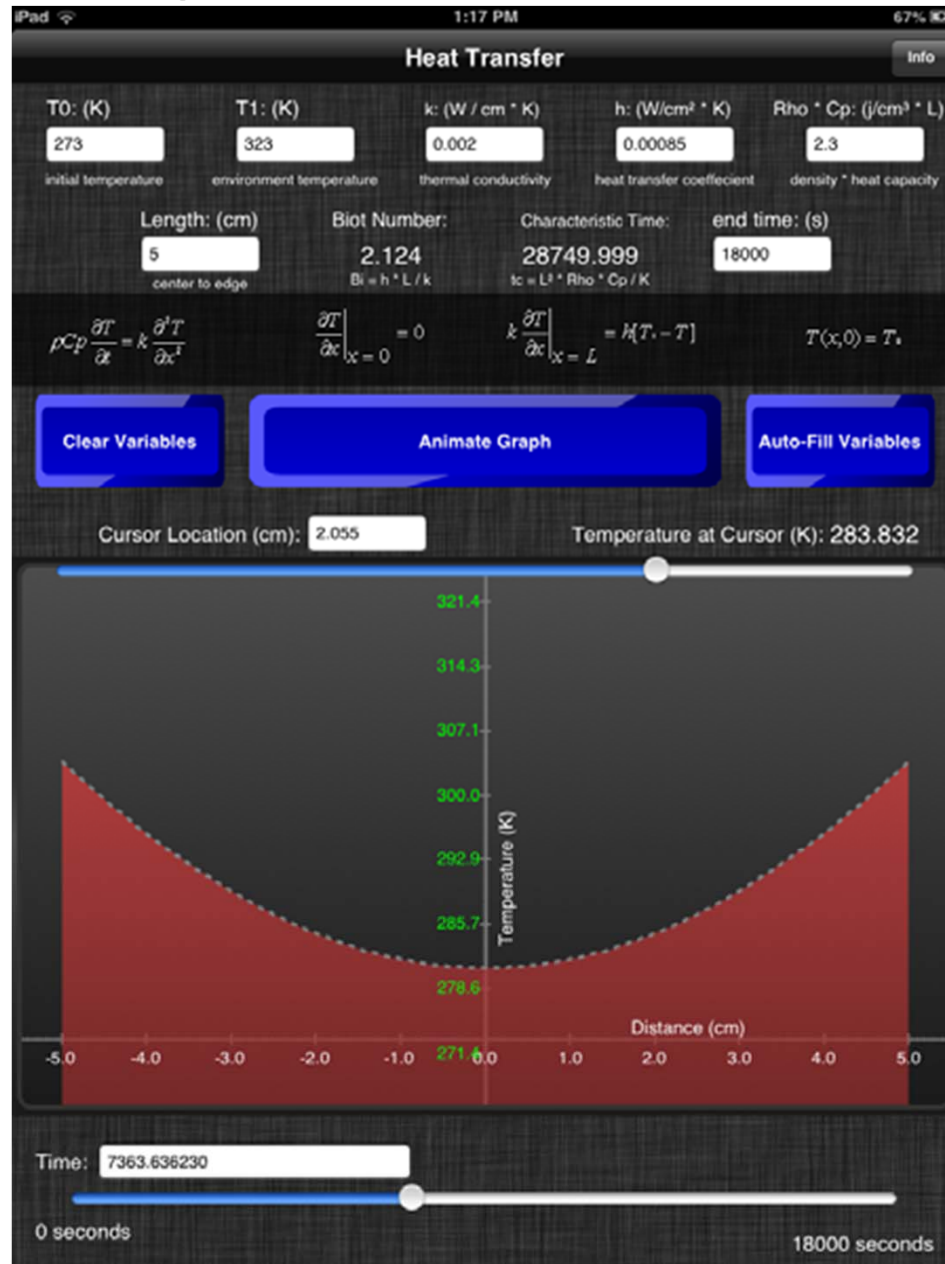
# App Development – iPhone Screenshots



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# App Development – iPad Screenshots



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# Implementation

- Reproduce example 5.3-2 of Geankoplis
  - Heat transfer in a slab of butter
  - Initial temperature,  $T_0 = 277.6$  K
  - Fluid temperature,  $T_f = 297.1$  K
  - Convection coefficient,  $h = 8.5$  W/m<sup>2</sup>K
  - Thermal conductivity,  $k = 0.2$  W/mK
  - $\rho C_p = 2300$  kJ/m<sup>3</sup>K
  - Half thickness,  $L = 4.6$  mm

# Implementation

- Reproduce example 5.3-2 of Geankoplis
  - Results
  - Biot number = 1.95
  - Heat conduction time  $t_c = 23000$  s
  - Simulation time  $t = 5$  hours
  - Temperature results match very well
  - App appeals to a wide range of learning styles
  - Inspires students to “learn the math”

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# Total Downloads

- **Total Downloads: 2651**
- USA: 1165
- UK: 146
- Canada: 101
- Thailand: 135
- India: 63
- Mexico: 67
- Turkey: 69
- Saudi Arabia: 60
- Italy: 51
- Brazil: 54
- "Others": 740

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# Summary

- This work has demonstrated an iPhone / iPad app called “Heat Transfer for Students”
  - Available for free from the app store
- Anecdotal evidence suggests that students have improved visualization of unsteady-state heat transfer by using this app
- Acknowledgments
  - James Worth Bagley College of Engineering
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  - Earnest W. Deavenport, Jr. Endowed Chair in Chemical Engineering
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