AC 2012-3043: FINITE ELEMENT ANALYSIS LEARNING MODULES FOR AN UNDERGRADUATE HEAT TRANSFER COURSE: IMPLEMENTATION AND ASSESSMENT

Prof. Kyle A. Watson, University of the Pacific

Kyle Watson earned his B.S. in mechanical engineering from Villanova University and his M.S. and Ph.D. in mechanical engineering from North Carolina State University. He has been a faculty member at the University of the Pacific since 2003 and has taught undergraduate courses in thermodynamics, heat transfer, combustion, air-conditioning, dynamics, and senior capstone design.

Dr. Ashland O. Brown, University of the Pacific

Ashland O. Brown is professor of mechanical engineering, University of the Pacific, and Principal Investigator. He has served as Dean for two engineering schools and headed groups at Ford Motor Co. and General Motors Corp., which included a product design section composed of product analysis engineers (finite element analysis experts). He has taught engineering courses in thermodynamics, solar engineering, graphics, dynamics, machine design, and finite elements methods. He has more than 50 referred technical research publications, and conference papers with 10 in the areas of finite element learning modules, with two recently accepted as referred engineering journal papers covering the results of the NSF CCLI-Phase 1 work.

Dr. Rachelle Kist Hackett, University of the Pacific

Rachelle Kist Hackett, Ph.D., is an Associate Professor in the Benerd School of Education within the Educational and School Psychology Department at the University of the Pacific, where she teaches graduate-level research methodology and applied statistics courses. In addition to serving as a consultant to faculty and students within her unit, Hackett serves as an independent evaluator on several state- and federally funded projects related to education.

Miss Alexis Pham, University of the Pacific

Alexis Pham is currently a Ph.D. student in educational psychology. She examines how students learn and develop in educational settings. She holds a M.A. in educational and counseling psychology from University of the Pacific.
Finite Element Analysis Learning Modules for an Undergraduate Heat Transfer Course: Implementation and Assessment

Abstract

Commercial finite element packages are widely used in industry thereby making exposure to this analysis and optimization tool an important component of undergraduate engineering education. Finite element theory and application has often been the focus of a graduate-level course in engineering programs, however industry demands are requiring B.S. engineering graduates to have skill in applying this essential analysis and design technique. To meet this need, finite element analysis (FEA) learning modules have been developed for implementation into various undergraduate engineering courses, including mechanics of materials, vibrations, heat transfer, fluid mechanics, and machine design and analysis; these learning modules have been designed to serve as an effective teaching and learning resource that reinforces fundamental concepts and applications of each course without requiring a knowledge of the rigorous mathematical theory underlying the finite element method nor the removal of course content in order to make room for this new material.

This paper discusses the implementation, results, impact, and assessment of incorporating these learning modules into an undergraduate heat transfer course using SolidWorks Simulation commercial software. The primary objectives of the learning modules are to provide the students with (a) an alternate insight into heat transfer concepts that are covered in a traditional undergraduate course, including steady-state heat conduction, transient heat conduction, and heat conduction through a semi-infinite medium, (b) a basic knowledge of finite element theory, and (c) the ability to apply commercial finite element software to engineering problems involving thermal systems. From an instructor’s point-of-view, the implementation of the learning modules should result in minimal impact on the course content and schedule by not requiring the elimination of other content in order to make room for the learning modules. Assessment has been done through the use of pre- and post-learning module quizzes and student opinion surveys and the results indicate that there is an increase in student performance and student satisfaction after having completed the learning modules.

Introduction

The finite element (FE) method is a widely used tool in industry for analyzing engineering problems. The most basic FE theory and applications are offered primarily as a graduate-level course, or in some cases, as an upper-level elective for undergraduate students. Therefore, the majority of engineering programs do not require coverage of FE theory and application as a component of their undergraduate curriculum. Industry is placing an increased emphasis on the ability to apply this powerful computational tool; so it follows that students earning an undergraduate degree in engineering should learn this skill in order to meet the demands of entry-level engineering job descriptions. The persistence of the deficiency of FE coverage in undergraduate engineering programs is due to various reasons, such as the recent focus on reducing credit-hours in engineering programs; the need to remove other course material at the expense of adding this new material; and the fact that FE
theory is very mathematics-intensive thereby making it more suitable for graduate students who have a more rigorous mathematical education. For example, a typical undergraduate heat transfer course within a mechanical engineering curriculum will cover the basic theory behind conduction (1-D, 2-D, and 3-D; steady-state and transient), convection (internal and external forced convection; natural convection), and radiation in one fifteen-week semester; this material comprises eleven of the fourteen chapters of Çengel and Ghajar’s textbook *Heat and Mass Transfer: Fundamentals and Applications*¹, including a chapter on “Numerical Methods in Heat Conduction” that provides a basic introduction on how to use finite difference techniques to approximate the heat conduction equation. Thus, the amount of material that needs to be covered in a heat transfer course makes it a challenge to spend an extensive amount of time covering FE theory and application without sacrificing other important course material. Regardless, there is clearly a need for knowledge of FE theory and application and undergraduate engineering curriculums should attempt to integrate this important topic into the existing curriculum.

This paper discusses the use of learning modules for delivering thermal FE instruction that can be easily integrated into a required mechanical engineering course. The early stages of these learning modules were discussed in a paper for a regional ASEE conference in 2009², while the current paper focuses on several refinements that have been made since the initial implementation, a new learning module related to heat conduction through a semi-infinite medium, and assessment of the pre- and post-learning module quizzes.

The need for integrating FE theory and application across the engineering curriculum has been established and methods have been suggested by other authors³-⁴. The primary focus of the current paper is to report the use of learning modules that would educate a broader spectrum of undergraduate engineering students with the basic knowledge of FE theory as applied to thermal analyses. Furthermore, students using these learning modules will gain experience in applying commercial FE software to solve engineering problems.

More details of the NSF-funded CCLI project that these learning modules are a component of can be found elsewhere⁵; in short, learning modules have been developed for several core engineering areas, including mechanics of materials, vibrations, heat transfer, fluid mechanics, and machine design and analysis. The current paper focuses in detail on the heat transfer component of this larger project.

The **educational objectives** of the heat transfer learning modules include the following:

- **a)** to provide a different insight into the heat transfer concepts that are covered in a traditional undergraduate mechanical engineering heat transfer course,

- **b)** to provide undergraduate engineering students with a basic understanding of FE theory as applied to thermal analyses, and

- **c)** to provide undergraduate engineering students with an ability to apply commercial FE software in order to solve thermal engineering problems by creating a valid model and understanding how to interpret and verify the results.
The **instructional objective** of the heat transfer learning modules is the following:

- **a)** to provide easily accessible thermal FE learning modules that require minimal instructor effort in order to integrate them into a required mechanical engineering undergraduate heat transfer course.

### Learning Module Summaries

#### Problem Descriptions

Two learning modules have been designed to meet the educational and instructional objectives outlined in the previous section. These learning modules are summarized below:

- **a)** A steady-state, two-dimensional heat conduction problem involving a long bar with fixed temperature, convection, and insulated boundary conditions.
- **b)** A transient heat conduction problem involving a furnace wall which can be modeled as a semi-infinite medium as long as the heat from the inside of the furnace has not penetrated to the exterior surface of the wall.

These two problems were chosen for the following two reasons:

- **a)** Both problems can be solved by performing hand calculations that involve theory that has been covered during the lecture portion of the course thereby allowing for a comparison between the FEA solution and the hand calculations that will allow for a verification of the FEA solution.
- **b)** The theory related to the hand calculations for both of these problems (i.e., numerical methods in two-dimensional heat conduction and transient heat conduction through semi-infinite mediums) have traditionally been challenging for students and an objective of the FE learning modules is to provide an alternative insight for students that will ideally make these topics easier to understand.

The problems for each learning module are summarized in Figs. 1 and 2. The steady-state problem (Fig. 1) was adopted from an exercise at the end of Chapter 4 (“Two-Dimensional, Steady-State Conduction”) of Incropera et al.’s textbook\(^6\), while the transient, semi-infinite medium problem (Fig. 2) was adopted from an exercise at the end of Chapter 4 (“Transient Heat Conduction”) of Çengel and Ghajar’s textbook\(^1\).

### Problem Solving Steps

After the introduction of the problem statement and summaries of the educational objectives and relevant FE and heat transfer theory, each learning module includes the following steps:

1. **Using SolidWorks to create a 3-D model.**
   The steps required to draw the model in SolidWorks are summarized, including creating a two-dimensional sketch and extruding the sketch to make a 3-D object and dimensioning the 3-D object. These elements of the learning module are presented such that a student with minimal background with SolidWorks will be able to model the problem.
A long bar of rectangular cross-section (0.4 m × 0.6 m) with a thermal conductivity of \( k = 1.5 \text{ W/m} \cdot \text{°C} \), is subjected to the following boundary conditions: two sides are maintained at 200°C, one side is insulated, and the remaining side is subjected to convection with the surrounding fluid at \( T_\infty = 30\text{°C} \) and \( h = 50 \text{ W/m}^2 \cdot \text{°C} \). Determine the temperature distribution in the bar and the heat transfer rate between the bar and the fluid per unit length of the bar.

**Figure 1:** Steady-state heat conduction problem description (adopted from Incropera et al.\(^6\)).
A 40-cm-thick concrete wall of a furnace is initially in thermal equilibrium with the surrounding air at 20ºC. When the furnace is fired, the combustion event creates an environment where the temperature of the inside surface of the furnace is instantaneously increased to 980ºC (i.e., the convection heat transfer coefficient in very large). Use SolidWorks Simulation to perform the following:

a) determine how long the wall can be treated as a semi-infinite medium.
b) determine the temperature distribution throughout the wall at a particular time.
c) determine the transient response (T vs. t) at a particular location inside the wall.
d) create an animation of the transient temperature distribution.

**Figure 2:** Transient, semi-infinite medium heat conduction problem description (adopted from Çengel and Ghajar⁴).
2. Creating a “Thermal Study” using SolidWorks Simulation.
   The steps required to create a thermal study for the 3-D part are summarized, including how to create a steady-state or transient study. For a transient study, the requirements for defining the transient conditions are summarized including the total time of study and the time increment.

3. Defining material properties.
   The steps required to assign the material properties which are necessary for a thermal analysis are summarized. Instructions for creating both custom-defined materials and common material types are included.

4. Defining the thermal boundary conditions and initial condition (only for the transient learning module).
   The steps required to define the thermal boundary conditions are summarized, including convection, specified temperature, heat flux, and adiabatic (zero heat flux) conditions. The transient learning module includes steps for defining the initial condition.

5. Meshing the model and running the study.
   The steps required to create a three-dimensional mesh using second-order tetrahedral solid elements type are summarized in addition to the simple step of running the finite element analysis.

6. Post-processing the FEA results.
   Information on post-processing the FEA results is included, including using a temperature probe to determine the temperature at any location, creating 3-D color plots of the temperature distribution, finding the transient temperature response at any location, and creating animations of the transient temperature distribution. For reference, the temperature distribution that results from the steady-state heat conduction learning module is included in Fig. 3 and a transient temperature response at a particular location that results from the transient, semi-infinite medium learning module is included in Fig. 4.

7. Comparing the FEA results to hand calculations.
   Information is given on how the problems can be solved by using hand calculations that involve either numerical methods (for the steady-state heat conduction learning module) or semi-infinite medium theory (for the transient, semi-infinite medium learning module); these topics have been covered during the lecture portion of the course and can be used as a comparison to the FEA solution thereby allowing for FEA verification.

8. Additional exercises.
   Additional exercises are suggested for further exploring the use of FEA in analyzing heat conduction problems. These exercises involve exploring the effects of mesh size and thermal conductivity on the temperature distribution and viewing isotherms.
Figure 3: Temperature distribution for the steady-state heat conduction learning module.
Figure 4: Temperature response for the transient, semi-infinite medium learning module (note the initial condition of 20°C).
Implementation

Both of the learning modules discussed above have been incorporated into an undergraduate heat transfer course at the University of the Pacific. All of the students in this class have taken a CAD course and the majority of students have taken a course in SolidWorks, but this is not required since the learning modules are written such that no familiarity with SolidWorks is necessary. The topics of heat conduction through semi-infinite mediums and numerical methods in heat conduction are covered before the learning modules are implemented. Specifically, finite difference techniques for one- and two-dimensional steady-state and transient heat conduction are covered using Chapter 5 (“Numerical Methods in Heat Conduction”) of Çengel and Ghajar’s text\(^1\) as a reference while Chapter 4 (“Transient Heat Conduction”) of the same text covers the theory behind semi-infinite mediums. With this knowledge, students are able to solve the learning module problems by hand and eventually compare the FEA output with these hand calculations. For the purposes of correlating data gathered across different measures and so as to collect information confidentially, each student is assigned an identifier (specifically, the names of animals are used); these animal ID identifiers are used in gathering the following information from the students:

a. Demographic data (e.g., class standing, major, gender, ethnicity, and GPA) are collected through the use of a survey administered on-line.

b. Similarly, information on student learning styles and personality types are collected by having the students take the following two surveys at the following websites:
   a. Myers-Briggs Type Indicator (MBTI): [http://www.humanmetrics.com/cgi-win/JTypes1.htm](http://www.humanmetrics.com/cgi-win/JTypes1.htm)
   b. Felder-Soloman Index of Learning Styles (ILS): [http://www.engr.ncsu.edu/learningstyles/ilsweb.html](http://www.engr.ncsu.edu/learningstyles/ilsweb.html)

c. The pre-learning module quiz is administered in class by the instructor who scores the quiz and submits the animal IDs and quiz scores to the evaluation team (see Appendix A).

d. The learning modules are assigned; this is accomplished by e-mailing the learning modules in the form of PowerPoint slides to the students and requiring them to complete each module.

e. Graded homework exercises are assigned to the students which require them to apply what they have learned from the learning modules. One assignment is given for each learning module (Figs. 5-6).

f. The post-learning module quiz (which is identical to the pre-learning module quiz) is administered in class by the instructor who scores the quiz and submits the animal IDs and quiz scores to the evaluation team.

g. A 15-question survey is administered where the students respond to questions with answers on a 5-point scale (Disagree; Partly Disagree; Neither Agree nor Disagree; Partly Agree; Agree). These questions can be seen in Appendix B along with the results.
Complete the Thermal Finite Element Analysis Learning Module: Steady-State Heat Conduction and submit the following: (50 points)

1. Perform the learning module and create a temperature plot.
2. Perform Exercise #1 on Slide 37 and create a second temperature plot.
   a. Compare the number of elements and nodes that result from this coarse mesh with your initial trial.
   b. Does the coarse mesh result in the same temperature distribution? Why or why not?
3. Perform Exercise #2 on Slide 38 and create a third temperature plot.
   a. What happens to the minimum temperature in the bar?
   b. Explain what has happened as a result of changing the thermal conductivity.
4. Perform Exercise #3 on Slide 39 and create a temperature plot that displays several isotherms.
   a. What occurs at the insulated boundary?

Be sure all of these SolidWorks Simulation print-outs are clearly labeled.

**Figure 5:** Graded homework assignment for the steady-state heat conduction learning module.
Answer the following after performing the **Thermal Finite Element Analysis Learning Module: Semi-Infinite Medium**: (50 points)

1. Create a thermal plot (in degrees Celsius) of the entire wall at 15 minutes.
2. Create a thermal plot (in degrees Celsius) of the entire wall at 45 minutes.
3. Create a plot of the temperature (in degrees Celsius) versus time at a location 10 cm from the inside of the furnace.
4. Create a plot of the temperature (in degrees Celsius) versus time at the midpoint of the wall.
5. Use SolidWorks Simulation to determine the time when the concrete wall can no longer be treated as a semi-infinite medium (clearly explain how you have determined this time).
6. Use analytical hand calculations to determine the time when the concrete wall can no longer be treated as a semi-infinite medium.
7. Change the wall to a material that has a lower thermal conductivity than concrete and remesh and rerun the study. Repeat #5 above.

**Figure 6:** Graded homework assignment for the transient, semi-infinite medium learning module.
Assessment and Discussion of Results

The primary method for assessing the success of the heat transfer learning modules is in using total correct scores on the pre- and post-learning module quiz. This quiz was designed primarily to assess the success of the learning modules in meeting the educational goal of providing a different insight into the heat transfer concepts that are covered in a traditional undergraduate mechanical engineering heat transfer course and thereby reinforcing the concepts by providing a more visual and “hands-on” exercise. The quiz consists of twelve multiple-choice questions (see Appendix A) and the same quiz is administered pre- and post-learning module and the results are tracked for each individual student through their Animal ID identifiers. The results from the spring 2011 semester are summarized in Table 1 below.

Table 1: Pre- and post-learning module assessment results.

<table>
<thead>
<tr>
<th>Paired t-test</th>
<th>Sample Size</th>
<th>Mean Score (out of 12)</th>
<th>Mean Score (%)</th>
<th>Std. Dev.</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-activity</td>
<td>11</td>
<td>7.00</td>
<td>58.3%</td>
<td>2.236</td>
<td>0.674</td>
</tr>
<tr>
<td>Post-activity</td>
<td>11</td>
<td>9.18</td>
<td>76.5%</td>
<td>1.079</td>
<td>0.325</td>
</tr>
<tr>
<td>Difference</td>
<td>11</td>
<td>2.18</td>
<td>18.2%</td>
<td>2.401</td>
<td>0.724</td>
</tr>
</tbody>
</table>

Percent Improvement: 31.2%

\[ t\text{-value}: 3.014 \]

\[ p\text{-value}: 0.013 \]

Although the sample size is small, the results indicate there is a 31.2% improvement (on average) from pre-quiz to post-quiz. Furthermore, the \( p\)-value of 0.013 indicates that there is statistical evidence to suggest that performance on the post-quiz will increase after completing the thermal FE learning modules.

The authors have investigated whether the change from pre- to post-activity depends on the personality style (e.g., MBTI “introvert” vs. “extrovert”) or learning style (e.g., ILS “sequential” vs. “global”). While comparisons were made using independent sample \( t\)-tests, the results were based on such a limited sample size to render interpretations questionable, at best. Therefore, the details of these statistically non-significant results are not reported at this time and await conclusions drawn in the future as sample size increases and statistical power becomes adequate. In actuality, non-significant findings would be considered desirable, as they would suggest the impact of the learning module is equally beneficial to all subgroups (based on the MBTI and ILS dimensions of personality and learning styles). The authors do not feel, however, that such a conclusion can be drawn given the limited statistical power of those analyses.

Finally, the 15-question survey shows that overall, students are showing satisfaction with the learning modules as they agreed with almost all (13 of the 15) of the positively worded statements. The results that are shown in Appendix B show that only two questions received scores below 3.9 out of 5. These scores are 2.73 for question #3 (Activities like these, and similar ones done by commercial finite element software vendors, are enough to understand finite element theory) and 3.40 for question #14 (These activities were more effective than using class time for lecture). Since one of the educational objectives of this study is “to
provide undergraduate engineering students with a basic understanding of FE theory as applied to thermal analyses,” and not for the students to become experts in FE theory, it is understandable that question #3 might receive a lower score.

The student survey results indicate that the implementation of the two heat transfer learning modules have been successful in meeting the educational and instructional objectives outlined in the “Introduction” of this paper. Specifically, the results from question #1 (These activities helped me understand thermal analysis in a conceptual manner; mean score 4.0/5) and question #4 (These activities demonstrate that an understanding of heat transfer theory can be reinforced with thermal analysis using finite element analysis; mean score 4.45/5) indicate that students are being exposed to a different insight into the heat transfer concepts that are covered in a traditional undergraduate mechanical engineering heat transfer course; the results from question #2 (These activities showed me that the finite element method determines an approximate solution for thermal analysis problems; mean score 4.73/5) indicate that students are being provided with a basic understanding of FE theory as applied to thermal analyses; and the results from question #10 (After completing these activities, I was able to implement a correct finite element model using commercial software; mean score: 4.45/5) indicate that students are being provided with an ability to apply commercial FE software in order to solve thermal engineering problems by creating a valid model and understanding how to interpret and verify the results.

From an instructor’s perspective, the instructional objective of providing easily accessible thermal FE learning modules that require minimal instructor effort in order to integrate them into a required mechanical engineering undergraduate heat transfer course has been met. The learning modules should be viewed as exercises which supplement the material covered in a traditional heat transfer course. Heat conduction in semi-infinite mediums and numerical methods as applied to thermal problems are typically covered in an undergraduate heat transfer course and these learning modules only require a small portion of one class to introduce them to the students before they perform them during their own time. Therefore, no material is sacrificed by including these exercises.

Conclusions

This paper reports the use of heat transfer learning modules in a required mechanical engineering undergraduate heat transfer course. Increasing industry demand for graduates to have the ability to use and apply commercial FE packages has created a need for integrating FE instruction into the undergraduate engineering curriculum. These learning modules provide a tool for easily implementing the FE method and application into the curriculum in order to provide a basic understanding of FE theory as applied to thermal analyses. Additional learning modules have been developed for other core engineering areas making the use of these learning modules across the engineering curriculum an excellent means for providing substantial coverage of the FE method. Furthermore, assessment of the results indicate that these learning modules are successful in reinforcing some basic heat transfer concepts while exposing students to FE theory as applied to thermal analyses. The results indicate that student performance (31.2% improvement from pre- to post-quiz) and student satisfaction (agreement with 13 of the 15 positively worded survey statements) have
improved through the implementation of these learning modules. It should be emphasized that these learning modules are not designed to make the students experts in FE theory; they are exercises that are designed to complement the lecture topics by providing a visual representation of a thermal problem while exposing the students to the basics of FE theory.

Acknowledgement

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Appendix A (Pre- and Post-Learning Module Quiz)

Pre/Post Quiz:
Thermal Analysis Finite Element Learning Module Activities

Animal ID: _________________

1. Which of the following is true for a semi-infinite medium:
   a) Heat conduction does not change with time
   b) Heat conduction is one-dimensional
   c) Heat conduction is multi-dimensional
   d) There will always be heat generation

2. Which of the following is true for a semi-infinite medium:
   a) Heat conduction results from the thermal condition at one boundary
   b) Heat conduction results from the thermal conditions at two boundaries
   c) Heat conduction results from the thermal conditions at more than two boundaries
   d) Heat conduction does not occur

3. A semi-infinite medium that is exposed to a moving fluid with a very large heat transfer coefficient has a boundary condition that can be treated as:
   a) A specified heat flux boundary condition
   b) A specified temperature boundary condition
   c) An insulated boundary condition
   d) A line of symmetry

4. A large plane wall that is initially at a temperature $T_i$ is suddenly exposed to a hot moving fluid on one side. When can this object be treated as a semi-infinite medium?
   a) Never
   b) Always
   c) For a finite period of time immediately after the object is subjected to the hot moving fluid
   d) For a finite period of time beginning some time after the object is subjected to the hot moving fluid
5. A large plane wall that is initially at a temperature $T_i$ is suddenly exposed to a hot moving fluid on one side and a cold moving fluid on the other side. When can this object be treated as a semi-infinite medium?

   a) Never
   b) Always
   c) For a finite period of time immediately after the object is subjected to the hot moving fluid
   d) For a finite period of time beginning some time after the object is subjected to the hot moving fluid

6. A two dimensional steady-state heat conduction problem requires how many boundary conditions in order to determine the temperature distribution?

   a) 1
   b) 2
   c) 3
   d) 4

7. An initial condition is not required in order to solve for the temperature distribution for which type of heat transfer problem?

   a) A semi-infinite medium problem
   b) A transient, one-dimensional problem
   c) A multi-dimensional problem
   d) A steady-state problem

8. The finite element method of modeling conduction heat transfer approximates a partial differential equation with:

   a) an ordinary differential equation
   b) a finite number of algebraic equations
   c) a series of finite numbers
   d) a finite number of elements

9. The finite element method of modeling conduction heat transfer results in an approximate solution for: (fill in the blank)


10. Two different objects ($A$ and $B$) are exposed to a hot fluid on their left side that results in one-dimensional, steady-state heat conduction. The thermal conductivity of object $A$ is double the thermal conductivity of object $B$. The temperature at the right side of object $A$ will be:

    a) higher than the temperature at the right side of object $B$
    b) lower than the temperature at the right side of object $B$
    c) the same as the temperature at the right side of object $B$
    d) unknown (it cannot be determined from the given information)
11. The temperature distribution throughout a solid body is shown below. Which of the following statements is true?

- a) this is a one-dimensional heat transfer problem
- b) this is a two-dimensional heat transfer problem
- c) this is a three-dimensional heat transfer problem
- d) it cannot be determined whether this is a 1-D, 2-D or 3-D problem
12. A top view of the temperature distribution from the solid body shown in the previous problem (problem #11) is shown below. Which type of boundary condition occurs at the bottom surface labeled below?

- **a)** a specified temperature boundary condition
- **b)** a heat generation boundary condition
- **c)** a convection boundary condition
- **d)** an insulated (zero heat flux) boundary condition
## Appendix B (15-Question Student Opinion Survey and Results)

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>Number of Student Respondents (n)</th>
<th>Percentage of Valid Responses (%)</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. These activities helped me understand thermal analysis in a conceptual manner</td>
<td>1 0 1 5 4</td>
<td></td>
<td>9.1</td>
<td>45.5</td>
</tr>
<tr>
<td>2. These activities showed me that the finite element method determines an approximate solution for thermal analysis problems</td>
<td>0 0 1 1 9</td>
<td></td>
<td>27.3</td>
<td>81.8</td>
</tr>
<tr>
<td>3. Activities like these, and similar ones done by commercial finite element software vendors, are enough to understand finite element theory</td>
<td>3 0 5 3 0</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. These activities demonstrate that an understanding of heat transfer theory can be reinforced with thermal analysis using finite element analysis</td>
<td>0 0 1 4 6</td>
<td></td>
<td>9.1</td>
<td>45.5</td>
</tr>
<tr>
<td>5. These activities helped me create the correct geometry to model a thermal analysis problem</td>
<td>1 0 2 3 5</td>
<td></td>
<td>9.1</td>
<td>45.5</td>
</tr>
<tr>
<td>6. These activities helped me identify the material properties required to model a thermal analysis problem</td>
<td>0 2 0 3 6</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7. These activities helped me to select suitable finite element types to model a thermal analysis problem</td>
<td>1 0 2 4 4</td>
<td></td>
<td>9.1</td>
<td>45.5</td>
</tr>
<tr>
<td>8. These activities helped me understand that the accuracy of the solution is dependent on the quality of the mesh</td>
<td>0 0 1 2 8</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* The means and standard deviations are based on coding responses of “Disagree” through “Agree” as 1 through 5, respectively.
### Appendix B (continued)

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>Number of Student Respondents (n)</th>
<th>Percentage of Valid Responses (%)</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disagree</td>
<td>Partly Disagree</td>
<td>Neither A or D</td>
<td>Partly Agree</td>
</tr>
<tr>
<td>9. These activities helped me to understand the correct boundary conditions to model a thermal analysis problem</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10. After completing these activities, I was able to implement a correct finite element model using commercial software</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>11. These activities helped me understand that it is important to verify that a finite element solution is correct through another independent method, such as hand calculations and/or experimental results</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>12. Personally witnessing and developing the finite element models in these activities on my own was better than a classroom demonstration</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>13. These activities were very clear and concise</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>14. These activities were more effective than using class time for lecture</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>15. I would like to learn more about using the finite element method to solve mechanical engineering design problems</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

* The means and standard deviations are based on coding responses of “Disagree” through “Agree” as 1 through 5, respectively.
Bibliography