Heat Transfer Activity for a First-Year Mechanical Engineering Course

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Abstract

A heat transfer educational activity is designed for freshman students who declare a mechanical engineering major. This activity is part of an introductory course given during the first year to introduce students to mechanical engineering and give them tools to use in while pursuing their Bachelors of Science degree in mechanical engineering.

The activity is designed to challenge students in learning heat transfer concepts. However, its rigor is planned for students (at the freshman level) who have not yet taken the prerequisites required for heat transfer.

The activity is scalable and can be easily deployed in other educational institutes. It is presented with its goals, goal attainment measures, and feedback representing the student perception.

1. Introduction

Mechanical Engineering Freshman II (MECH 1208) is an introductory class offered to freshman students during their second semester at the University of Texas at Dallas [1]. It is offered to students who have declared a mechanical engineering major. The goal of the introductory course is to help students learn concepts in mechanical design, forces and stresses, engineering materials, motion and power transmission, and thermal and energy systems. The course has several different activities, one of which is described in this paper. The goal of this particular activity is to cover the heat transfer portion of the class.

Activities are often used to help clarify concepts of heat transfer that are difficult to explain in a lecture style course. The activities can include rigorous learning experiments [2], or the use of low cost desktop-scale apparatus [3], or design and build prototypes [4], or studying the cooling effects of crushed or solid ice [5], or other experiments. Numerical assignments using Excel are used [6]. Numerical and experimental projects are also presented [7] where ANSYS was used for the numerical simulations. The benefit of these activities are in enhancing the student's understanding [8] or in repairing misconceptions in heat transfer. They can be highly effective at the junior level [9] and improve the student's interest in heat transfer [10].

A heat transfer activity for first year mechanical engineering students is presented here with an appropriate rigor for freshman students who are not yet introduced to prerequisites that can make heat transfer concepts palatable.

The goal of this activity is presented. The problem statement is provided followed by a description of the support materials that provide scaffolding to freshman level students as they work on the activity. A section on goal attainment is presented. Finally, the student perception of the activity is captured by a survey and provided.

2. Goals

The goal is for students to learn, at the freshman level, that there are governing equations used by engineers to simulate heat transfer. When solved, these equations can predict the transient temperature of a part.

1) With certain assumptions, the equations can be solved analytically. The analytical solution can be plotted as an X-Y plot where the plot title, axes labels, and units are to be clearly shown.
2) It is also possible to create thermal simulations to solve the governing equations using numerical methods. The simulations can be used in the presence or absence of analytical solutions. Sensors can be added in the simulations to yield an X-Y plot similar to that obtained with the analytical solutions.

The plot obtained analytically matches that obtained numerically only if the assumptions are correct, the analytical solution is obtained appropriately, and the simulations are performed properly.

2. Problem Statement and Support

An initial value problem is selected for this activity. A sphere is specified to have a given diameter and initial temperature. It is subjected to constant convection cooling and cools to room temperature over time following a temperature versus time chart similar to the one shown in Fig. 1.

A 50-minute lecture is given to explain the conduction and convection modes of heat transfer. Since cooling a sphere due to convection has an analytical solution for $Bi < 1$, the governing equations and their analytical solution are provided to the students.

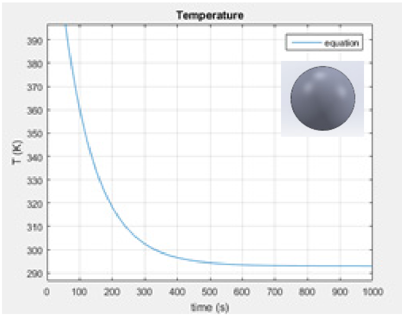

Fig. 1, Temperature versus Time Chart for a Sphere in an Initial Value Problem

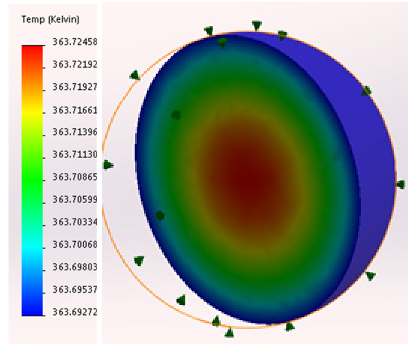

Fig. 2, Temperature Contours in the Sphere

The heat transfer equation in case Bi < 1 is given as follows [11]:

$$mc\frac{dT(t)}{dt} + hA_s\left(T(t) - T_\infty\right) = 0$$

The first term of this equation is time dependent. In this first term, m is the mass of the sphere, c is the specific heat of the sphere, T(t) is the time dependent temperature of the sphere, and t is the time.

The second term represents the convection heat loss at the outer surface of the sphere. In the second term, h is the convection coefficient, A_s is the surface area of the sphere, and T_∞ is the temperature of the cooling fluid medium.

The analytical solution of this equation is as follows, where T and Ti are the transient temperature and the initial temperature of the sphere, respectively [11]:

$$\frac{T - T_\infty}{T_i - T_\infty} = \exp\left[-\left(\frac{hA_s}{\rho V c}\right)t\right]$$

The students are asked to generate a plot of temperature versus time using the analytical equation using MATLAB.

A tutorial is given to help students draw a sphere with the given diameter in SolidWorks and define its physical properties. The thermal simulation application of SolidWorks is used to set the initial condition, a convection boundary condition, an ambient temperature, and run a transient heat transfer simulation. The students plot instantaneous contour plots of the temperature in the sphere to observe a hot center of the sphere and a cooler surface temperature (Fig. 2). However, since Bi < 1 the conduction heat transfer in the sphere makes the difference between the highest and coolest temperature very small.

The students are also asked to add a transient sensor in the simulation and plot the average temperature of the sphere versus time.

Comparing the temperature versus time curve obtained by SolidWorks to that obtained using the analytical equation can show quite a difference when there is an error in the calculations. However, when the calculations are correct, the curves are found to have excellent agreement.

3. Goal Attainment

Engineering reports provided by the students indicate a high level of attainment of the goals set for the activity. The freshman students were able to plot the temperature of the sphere and they were able to perform the numerical simulation. They provided meaningful conclusions.

One student wrote, “Copper is very conductive so the [temperature] variation throughout the sphere is minimal which was expected knowing the properties of Copper. It’s very low Biot Number makes it a good conductor it cools evenly throughout the solid.”

Another wrote, “From the initial temperature, the copper sphere cools at a rapid rate until reaching ~320K. After, it takes significantly longer to cool down.”

Questions were included in an exam regarding the meaning of the Biot number, the difference between conduction and convection, and the cooling phenomenon. Most students were able to answer the questions correctly.

4. Scalability

The activity is implemented in classes of 48 students and other classes of over 200 students. The activity is scalable and can be applied in any mechanical engineering freshman class. It is found to have no limitations based on the class size as long as computers are available with the SolidWorks or equivalent software as the students work in teams of two.

5. Student Perception

A survey is used to capture the student’s perception of the activity. Results of the survey indicate the activity is well enjoyed, appreciated, and valued by the students.

The survey was administered in the spring semesters of 2017 and 2016. It was also administered in the fall semester of 2016. The number of students involved in the surveys are shown in Table 1.

Table 1, Number of Students Involved in the Surveys

Semester	Students	Surveys Completed
S’17	221	153
S’16	237	151
F’16	48	22

The following statement is given in the survey: "I understand how a solid body can cool down due to convection." Students responded as shown in Fig. 3 during the three semesters when the survey was given.

Even though the work was in simulation form and not physical, the students were able to observe the cooling process and generate temperature versus time plots. At the end of this activity, the freshman level students felt they understood the cooling phenomenon.

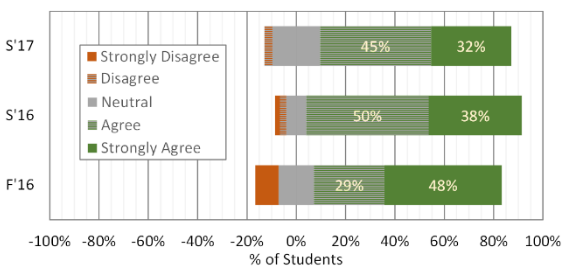

Fig. 3, Student's Response to Understanding How a Solid Body Can Cool Down

The students enjoyed the activity. They responded as shown in Fig. 4 to the following statement: "I enjoyed working on this activity."

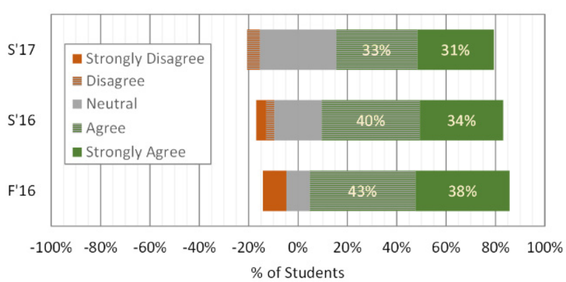

Fig. 4, Student's Response to Enjoying the Activity

The students also considered the activity of value to them. They responded as shown in Fig. 5 to the following statement: "The concepts I learned while working on this activity will be of value to me."

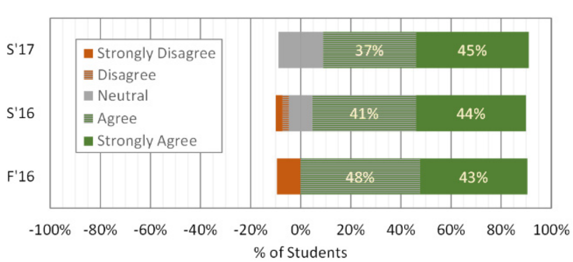

Fig. 5, Student's Response to the Value of the Activity

6. Summary

A project presented here for first year students with declared mechanical engineering major. The goal of the project is to introduce the freshman students to heat transfer. The project is considered effective in meeting its goals. At the conclusion of this activity, students were able to draw meaningful conclusions and answer exam questions related to heat transfer. The students enjoyed the activity and considered it valuable.

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