Stronger Student Engagement in the Undergraduate Heat Transfer Course through a Numerical Project

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Abstract

A numerical heat transfer project was used to complement a conventional heat transfer lecture course and its corresponding heat transfer lab. The numerical project helped students relate to the heat transfer course material and improved their engagement. The students were observed to exchange ideas and help one another with understanding heat transfer concepts. Student's response, obtained from a survey, revealed a desire to perform numerical projects in addition to attending lectures and performing physical experiments.

Keywords

Numerical, Heat Transfer, Project.

Introduction

A heat transfer three credit hour lecture course (MECH 3320) is offered to junior level mechanical engineering students at the University of Texas at Dallas. It is followed by a heat transfer lab (MECH 3120) where students conduct physical experiments that deal with the modes of heat transfer. The course and its lab cover the traditional learning outcomes of heat transfer that are required in a mechanical engineering curriculum. A numerical project, which is subject of this paper, was offered during the summer semester of 2016 as part of the lecture course (MECH 3320).

Projects are often used to help clarify concepts of heat transfer that are difficult to explain in a lecture style course (Cirenza et. al.[1]). These projects can include rigorous challenge-based learning experiments (Cirenza et. al.[1]) or the use of low cost desktop-scale apparatus (Recktenwald[2]) or design and build projects (Sozen[3]) or other experiments. Numerical projects using Excel are presented by Edwards and Lobaugh[4]. Numerical and experimental projects are also presented by Hossain et. al.[5]. Students benefit from the projects which can help in teaching (e.g., above referenced papers) or to repair misconceptions in heat transfer (Prince and Vigeant[6]).

The numerical project presented in this paper included multiple deliverables relating to steady state conduction, convection, and radiation heat transfer. Well-defined and open-ended deliverables were requested as described below.

The students were asked to work on the project individually and submit individual reports. However, they were encouraged to help one another and discuss results among themselves. The students were observed to interact professionally during the project and seemed to have a genuine interest in obtaining and discussing results inside and outside the classroom.

A survey, intended to capture the student's feedback, indicates the project was well-received and appreciated by the students. The student's comments and answers to survey questions are presented in this paper.

The Well Defined Deliverables

The project's well-defined deliverables were based upon a round bar used to conduct heat. The bar was held at a constant temperature at one end and a different temperature at the other end. All other surfaces could be insulated (case 1), subjected to convection heat transfer (case 2), or subjected to convection and radiation heat transfer (case 3). The students were asked to calculate the temperature profile in the bar and include all their calculations and justification for their selected conduction, convection, and radiation parameters.

The project required that the material of the bar shall be non-uniform along its length. For example, the first segment of the bar shown in Fig. 1 could be stainless steel, the middle segment could be copper, and the last segment could be stainless steel or any other material.

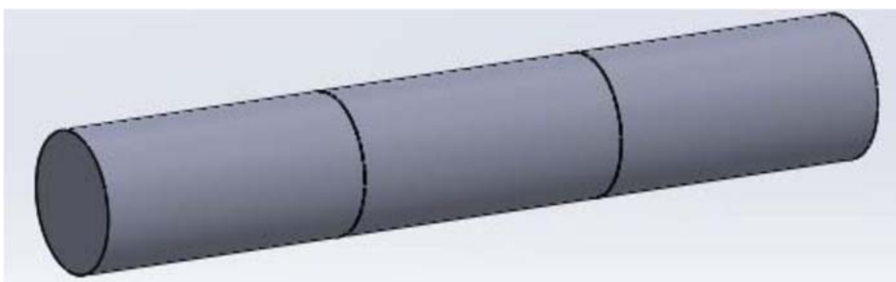
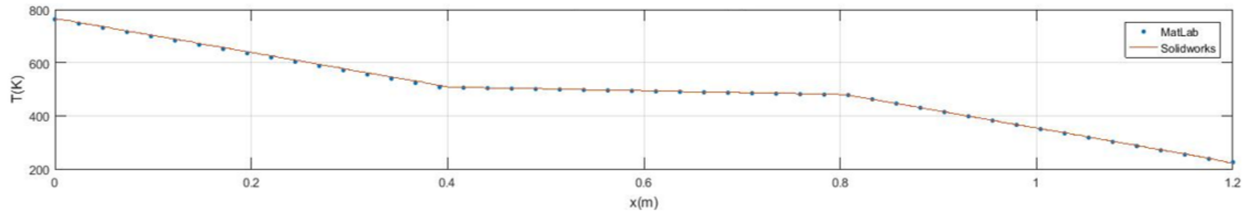


Fig. 1, The Composite Round Bar

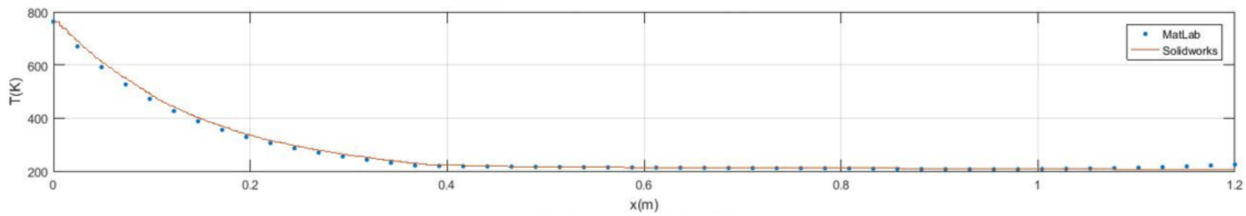
The students were given access to the SolidWorks heat transfer application. Since the students' expertise with using 3D modeling varied, a complete and step-by-step tutorial was provided to generate the solid assembly, generate the mesh, set the boundary conditions, run the model, and generate a temperature profile along the axis of this round bar in SolidWorks. The tutorial also addressed mesh independence and numerical convergence. While Kurowski[7] offers an excellent book on developing such a simulation in SolidWorks, the given instructions in this project were significantly more detailed and specific.

The students were also given a MATLAB script that handles one-dimensional heat conduction without convection or radiation. They were asked to run the MATLAB script and compare its results to those of the SolidWorks numerical simulation for identical boundary conditions. The students were asked to give comments regarding the similarity or differences between the results of the MATLAB script and the three dimensional simulation as shown in Fig. 2(a) for the round bar.

The students were given the opportunity to derive numerical equations (based on Bergman et. al.[8]) and implement them in the given MATLAB script to account for convection and radiation along the outer surface of the bar while the ends of the bar were held at the original given temperatures. The students worked on this and provided results similar to those of Fig. 2(b). Here, the students were also asked to calculate a representative Biot number and justify the use of a one dimensional heat transfer script for their materials selection.



(a) Conduction Only



(b) Conduction, Convection, and Radiation

Fig. 2, Superimposed Results of SolidWorks and MATLAB

The Open-Ended Deliverable

Upon completion of the well-defined deliverables, the students were asked to implement any geometry of interest. They were also asked to find a way to compare their results to those of the well-defined deliverables if applicable. No other constrains were given to the students for completing this open-ended deliverable. For this reason, numerous different designs with a highly varying degree of difficulty were presented.

Some students slightly varied the cross-section of the bar (e.g., they used hexagonal bar or square bar) or they added a layer of insulating material on the outside of the original round bar. They calculated the temperature distribution along the length of the bar and were able to compare their temperature distribution to those obtained in the well-defined deliverable. Within this group, several students experimented with different convective medium temperatures and different surrounding radiation temperatures to satisfy their own interests. They looked at the temperature profile in the bar as they changed the boundary conditions and the heat transfer coefficients.

Other students used complex geometries (e.g., car tire rim, bicycle tire, or frying pan). They calculated the three-dimensional temperature distribution with conduction only. Then, they added convection and radiation and re-calculated the temperature profiles. Some created reference lines within the geometry and made observations regarding the temperature profiles along their lines while convection and radiation were turned on and off.

Student's Feedback

Thirty three (33) students took the heat transfer course during the summer of 2016. Among these, 32 completed the project and were offered to voluntarily complete the survey. Thirty (30) responses were collected and the feedback, based on their answers, is presented here.

The results shown in Fig. 3 illustrate the students unanimously liked having a numerical project in the course. Approximately 80% think such project should be assigned in the future and the majority consider modeling and simulation a valuable learning experience that should be incorporated in more courses.

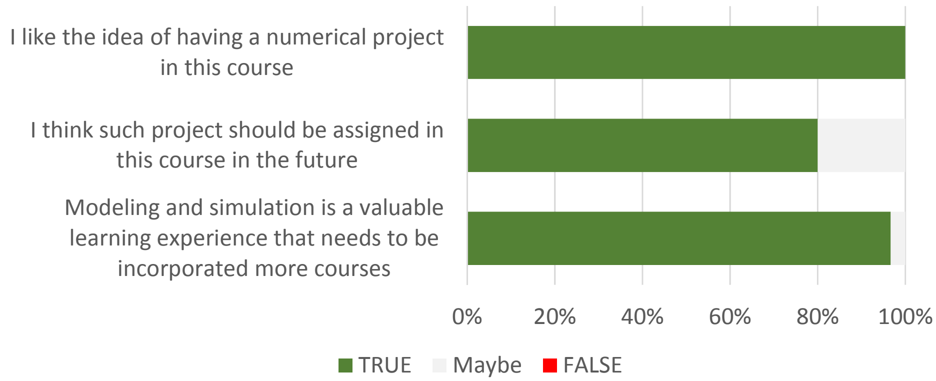
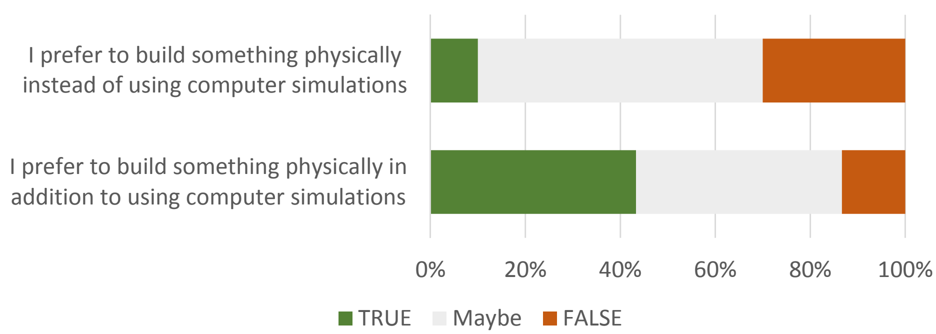


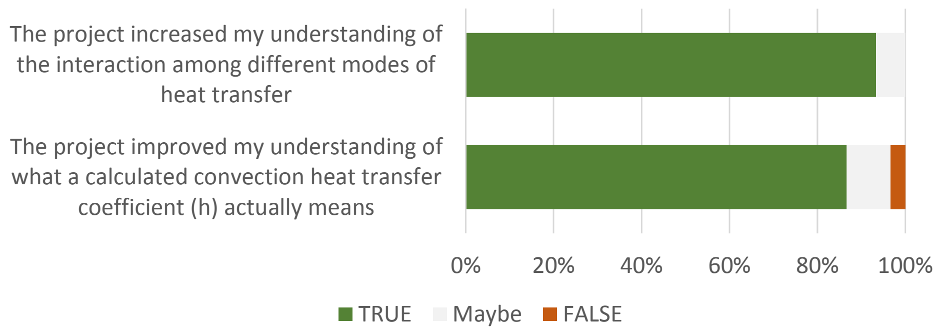
Fig. 3, Student Feedback on Numerical Projects

When asked if they prefer to build a physical experiment instead of (or in addition to) a numerical model, approximately half the students answered "maybe" as shown in Fig. 4. However, the students would prefer physical experiments to be accompanied by numerical simulations.



Fig, 4, Students Feedback on Physical Projects

As students changed the boundary conditions and the physical properties, the majority responded (Fig. 5) that they have gained a better understanding of the modes of heat transfer and what some variables mean.



Fig, 5, Students Feedback on the Learning Outcome

The project was assigned on the first week of the semester and was due on the week before the end of the semester, which means more time could not have possibly been given. Yet, a few students needed more time and considered the timeline may have been too short (Fig. 6). This may have been caused by other homework and exams that were used to cover the learning outcomes of the course.

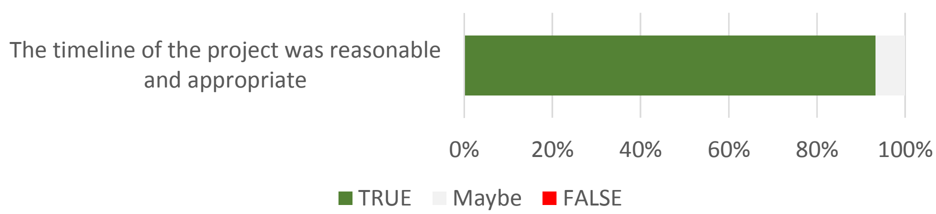


Fig. 6, Students Feedback on the Project Timeline

In regards to team work, the project required individual work. When asked if they prefer to do such a project as a team, only a few preferred to work as a team. The majority were unsure or did not prefer to do so as shown in Fig. 7.

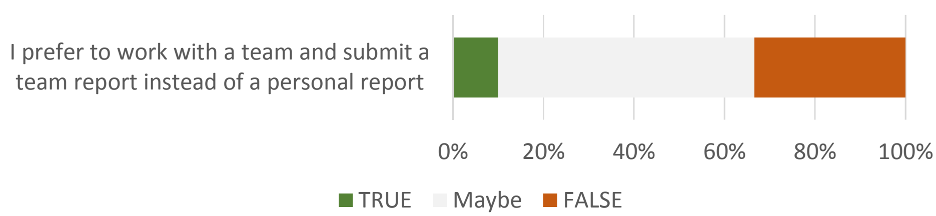


Fig. 7, Students Feedback on Teamwork

When asked if they prefer well-defined project deliverables (deliverables 1, 2, and 3) versus an open ended deliverable (deliverable 4), the students preferred the well-defined project deliverables as shown in Fig. 8.

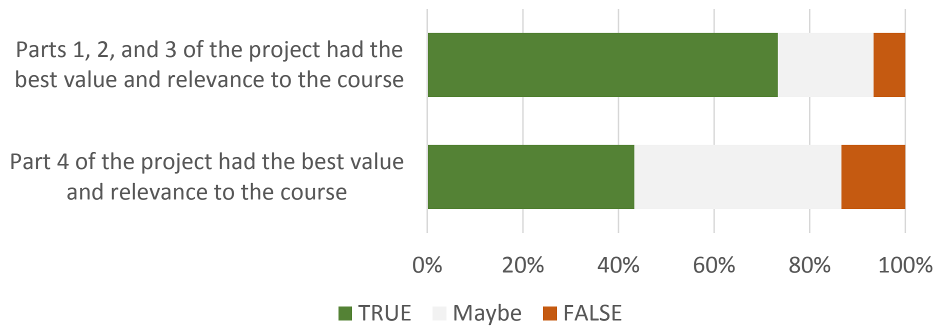


Fig. 8, Students Feedback on Teamwork

Student's Comments

Additional feedback was requested in the survey about the most challenging and the most/least enjoyable parts of the project. Suggestions and comments were also requested. The most notable answers are summarized below.

Most students expressed their interest in working with a simulation program. One student wrote the most enjoyable part of the project is: "seeing how the simulations work and tying that into the report." Another student enjoyed: "changing values and running multiple models; seeing the drastic changes of using different materials."

A common theme for the least enjoyable part of the project was data management: exporting data from the three-dimensional program (SolidWorks) and superimposing this data (using MATLAB or Excel) onto the MATLAB results. Students also considered a common challenge was developing a plan on what exactly to do in order to complete each deliverable.

Regarding additional suggestions and comments, one student wrote: "We should be encouraged to work on the project as we cover relevant materials." Another student wrote: "It was a very good learning experience. I think other semester students should get to enjoy it too." Another wrote: "It was useful to understand the concept of convection and radiation in heat transfer." One student wrote a comment that summarized it all. The student wrote: "Enjoyed it a lot!"

Conclusion

A numerical project was given to complement the undergraduate heat transfer lecture course. The project gave students an opportunity to examine the effects of different parameters on the temperature profile in a solid object. Students worked individually but were able to discuss their results throughout the semester.

Based on a post-project survey, students considered the project helpful to better understand the interaction among different modes of heat transfer. They liked the idea of having a numerical project in the lecture course and most students recommend keeping the numerical project in the heat transfer course in future semesters.

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