Use of COMSOL in a Thermodynamics Course to Enhance Student Learning

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***Abstract*— Student involvement in research activities increases faculty/student interaction both inside and outside the classroom, increases student involvement in their learning, and makes difficult coursework more relevant. This paper describes how the authors introduced computer simulation in a thermodynamics class to supplement theoretical knowledge and help students master concepts learned in the classroom. Energy-related projects to be simulated using COMSOL software were assigned to students and research reports were produced at the end of the semester. A survey conducted over two semesters highlighted how the inclusion of such projects enhanced student learning.**

Keywords—Computer simulation, Comsol, Thermodynamics

I. INTRODUCTION

Enhancing learning through research experiences for undergraduate students has been a subject of a number of reports from educators and researchers; different pedagogies and practices have been shown to improve student participation. There is broad recognition that meaningful learning in engineering requires that students master fundamental concepts, rather than memorize facts and formulas [1, 2]. An extensive literature demonstrates that traditional educational methods are frequently ineffective for addressing fundamental student misconceptions [1, 3-8]. Studies have shown that student participation in research activities helps them visualize their academic careers, increases their productivity, and has an overall impact on their college success [9]. This study also showed that research at the undergraduate level helps with retention and encourages students to pursue graduate studies. In addition, the use of inquiry-based activities effectively addresses misconceptions held by undergraduate engineering students [10].

Many technological advances (such as laboratory equipment, software, etc.) have not only enhanced classroom teaching and learning but also helped students to think critically; in addition, these advances have been used to assess student performance. However, the rapid rate of change in technology fields poses challenging problems for academic institutions, specifically for the engineering disciplines. The main problem is the provision of relevant and meaningful practical experience where laboratory resources such as hardware and infrastructure are limited [12, 13]. Often, engineering equipment is costly, and adding more credits and hours to an already packed curriculum is impractical and costly. For that reason, some institutions have embraced virtual testing/simulation using computer software; computer-based learning tools have been shown to pique student interest, excitement, and motivation [13]; resulting increased student engagement in the learning process [14]. Studies [15] have shown that well-designed simulation software has a positive impact on student thinking and learning. In a virtual environment, students have the opportunity to interact with and understand complex phenomena that would otherwise be inaccessible in a traditional classroom [16].

Simulations [14, 17] can provide a more efficient learning method in certain fields, allowing students to visualize abstract/ theoretical models and concepts [15]. In [20] faculty at the University of Waterloo described how the incorporation of COMSOL simulations to supplement a lecture course in electrochemical engineering reinforced and brought life to many of the concepts covered in the lectures.

Well-designed simulation software may also help develop students' spatial ability [14, 15]. The concept of visualization is natural and familiar, encountered in teaching children at the earliest stages in their lives how to count by using manipulatives. Students continue to use spatial ability to play video games, to rearrange their rooms, and to assemble furniture (i.e. computer desks) and home electronic equipment. Spatial ability is very important for careers in engineering and the physical sciences [18, 19].

Another aspect of undergraduate student success is apparent in measured improvement in critical literacy and oral communication. At the end of the course, students should be able to articulate and present challenging and abstract topics learned in class. When students are taught how to write summary reports and make cogent presentations in an engineering laboratory, they were able to produce high-caliber work and engage in mature self-criticism [11].

Exploring and implementing new approaches such as experiential learning in a traditional classroom may provide a strong motivating factor for student success. Using simulation technology in the classroom keeps students motivated [16], improves their critical thinking skills, and helps the students master concepts instead of techniques.

II. THERMODYNAMICS COURSE

In a thermodynamics course, students are introduced to basic physical concepts and applications of thermodynamics, and their consequences for engineering processes and operations. During prior semesters, the course was taught in a traditional way where knowledge was conveyed primarily by lectures and problem-solving sessions were conducted at the end of each chapter. In addition to tests and quizzes, a semester long research paper was assigned on application of thermodynamic principles to an existing or emerging technology; topics included seismic isolator, magnetic cooling, superconductivity and superfluidity, hydrogen powered vehicles, bio-fuels and photovoltaic cells. Although the term paper was staged, student engagement level was not encouraging. Consequently the research paper was replaced by a computer simulation research project in which students simulate an energy changing process and analyze how energy change or transfer do occurs and how theoretical principles from the classroom compare/contrast class with simulation results. Students were required to use the additionally scheduled lab hour for the simulation research project.

III. COMPUTER SIMULATION PROJECT

At the beginning of the semester, a computer simulation project was assigned to students. The project required COMSOL software that students had never used before. COMSOL is an interactive simulation software using finite element analysis for solving multi-physics based problems that be described/defined by partial differential equations. COMSOL has several toolboxes that in particular allow the user to simulate/solve problems related to electrical systems, computational fluid dynamics, acoustics, heat transfer, and pipe flow—coupled with other phenomenon. It also allows the user to interface with other engineering software such as AutoCAD, Pro-Engineer, SolidWorks, and Matlab for further modeling and analysis. The results are often presented in geometrical/visual form for easy interpretation. This software lends itself easily to the analysis of research-based problems in courses such thermodynamics. In and of itself COMSOL is quite user-friendly, so the main challenge was to introduce students to finite element analysis and make sure they understood the simulation process i.e. the steps involved, how to adjust different parameters to represent the physical problem, and how to interpret the results.

After the students were introduced to finite element, the next phase was to vet them on COMSOL software: students were first divided in groups of two, mainly to facilitate collaboration (teamwork). One of two tutorial examples—heat transfer through a solid cylinder or heat propagation during the breaking process—were then assigned to the groups; since the tutorials provided all the steps, students were able to effectively navigate and learn the software.

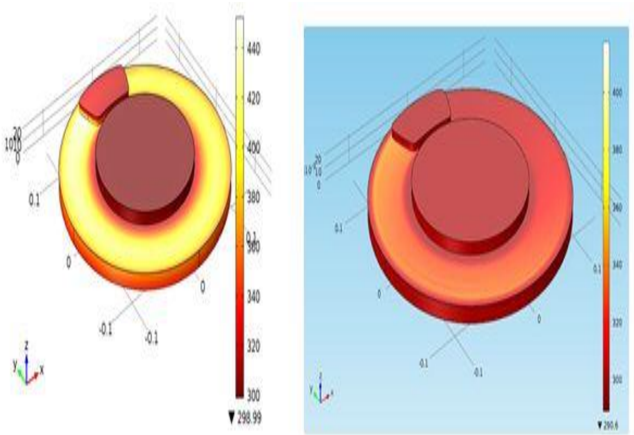
When students were comfortable with the simulation process, minor changes were made to the assigned tutorials: in the case of heat transfer through a solid cylinder, students were asked to add a thin layer of a different material than that of the surrounding cylinder; in the case of heat transfer during the breaking process, students were asked to add a thin layer of lubricant between the brake pad and the disk. For both modified projects, each group was given a different material or lubricant.

IV. PROJECT REPORTS

The purpose of this project was threefold: learning computer simulation using COMSOL software, connecting theoretical knowledge from the classroom to simulation results and writing a technical report writing, the second being the main goal.

As the semester progressed, student interest in computer simulation was apparent as their engagement increased; in addition, simulation reports from the students highlighted what they learned while using COMSOL, analyzed simulation results, and showed the connection between what they learned in the class and the computer simulations.

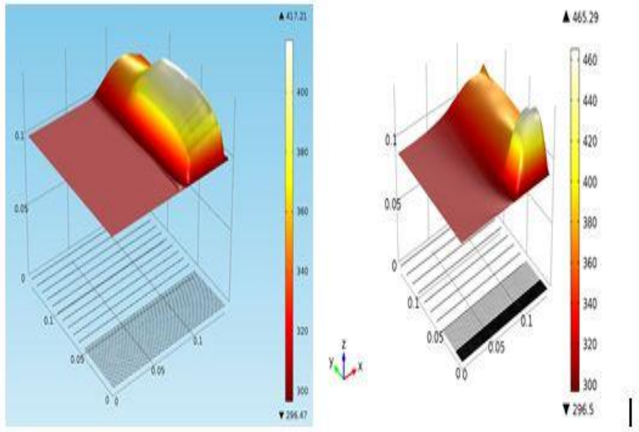
Fig. 1, taken from one student report, shows the temperature distribution in both the disk and the breaking pad for both cases: the first case being that of the breaking pad and disk, and the second arising when a lubricant layer, 2mm of Polytetrafluoroethylene (PTFE), was added on top of the disk.



(a) (b)

Figure 1: Surface temperature profile for (a) plain disk and breaking pad, and (b) disk and pad with a 2mm layer of PTFE on top of the disk.

In Fig. 2, it can be seen that the maximum temperature is approximately 450K (Fig. 2.a) and when a PTFE layer was added, the maximum temperature is approximately 420K (Fig. 2.b).



(a) (b)

Figure 2: Temperature profile for (a) plain disk and breaking pad, and (b) disk and pad with a 2mm layer of PTFE on top of the disk.

Over the course of two semesters, overall student satisfaction was assessed using a 5-point anonymous survey (ranging from strongly agree to strongly disagree) that was administered toward the end of the semester. Student responses as well as the questions they responded to are shown in Fig. 3 below.

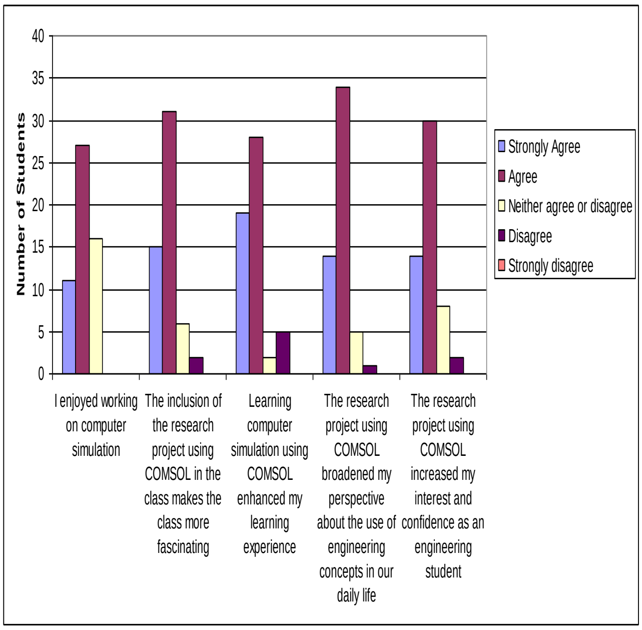


Figure 3: Students survey results

As illustrated in the above chart, students responded positively to the inclusion of the computer simulation project. The authors wish to point out that student response to the first question "I enjoyed working on computer simulation" is mixed, with a considerable number of students neither agreeing nor disagreeing; this can be attributed to the learning of new software coupled with the course load and time constraints.

V. CONCLUSION

The use of computer simulation is a powerful tool to illustrate how finite element analysis software can be used to simulate real life scenarios. In the authors' thermodynamics class, computer simulation projects were included to help students not only learn about finite element analysis but also realize how theoretical knowledge they learn in the classroom translates to real life applications. A survey conducted at the end to assess student satisfaction regarding the overall experience produced positive evidence that the inclusion of research projects enhanced their learning experience. Future work will analyze how the inclusion of the abovementioned simulation projects affected student performance over multiple semesters.

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