The Enhancement of Students Learning Through COMSOL Simulation Projects

Yves Ngabonziza and Hendrick Delcham

Abstract - **Research has shown that student participation in research activities increases faculty/student interactions outside the classroom, increases student involvement in their learning, addresses different learning styles, provides opportunities to see the entire academic pipeline, and makes difficult coursework more relevant. As educators, we are always looking for ways students can enhance their learning; one possibility is to link the theoretical knowledge we provide to them in the classroom with, not only real life applications, but also with job market requirements they will face once they graduate. This paper describes how the use of computer simulation was introduced in Thermodynamics class to supplement and help students visualize theoretical knowledge they learned in the classroom. Two energy related projects to be simulated using COMSOL software were assigned to students; post-class reports and survey highlighted how the inclusion of the computer simulation projects in the class enhanced students' learning.**

Index Terms: **Computer simulation, Comsol, learning, thermodynamics**

I. INTRODUCTION

Enhancing learning and research experiences for undergraduate students has been a subject of a number of 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 the memorization of facts and formulas [1, 2]. An extensive literature demonstrates that traditional educational methods are frequently ineffective for addressing fundamental student misconceptions [1, 3-8]. Research has 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 [9]. 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 the classroom teaching and learning but also helped students to think critically; in addition, these advances have been used to assess students' performance. However, this 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 equipments are costly, and adding more credits and hours to an already packed curriculum is impractical and too costly to students. In that regard, some institutions have embraced the use of virtual testing/simulation through computer software; the use of computer-based learning tools have been shown to increase student's interest, excitement, and motivation [13]; it also showed a higher students' engagement in their learning [14]. Studies [15] showed that well-designed simulation software has positive impact on students thinking and learning. In such environment, students have the opportunity to interact with and understand complex phenomena that would otherwise be inaccessible in a traditional classroom (16).

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Simulations [14, 17] can be a more efficient method for learning in certain fields. Simulations [15] allow students to visualize abstract/ theoretical models and concepts.

A well-designed simulation software may also help develop students' spatial ability [14, 15]. The concept of visualization is natural in teaching children at the earliest stage in their lives how to count by using manipulative. Students continue to use their spatial ability to play video games, to rearrange their room, and to assemble furniture (i.e. computer desks) and home electronic equipment. Spatial ability is very important for career paths such as engineering, and science [18, 19].

Another aspect of undergraduate student success is registering gains in critical literacy and oral communication. At the end of the study, students should be able to articulate and present different topics they learned in class. When students received guidance about making reports and presentations in an engineering laboratory, they were able to produce proper documents with high accuracy and a sound sense of self criticism [11].

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

II. THERMODYNAMIC COURSE

During the thermodynamics course, students are introduced to basic physical concepts and applications of thermodynamics, and their consequences for engineering processes and operations.

During the course of prior semesters, the course was taught in a traditional way where lectures were the main components of the course and problem solving sessions were conducted at the end of different chapters. In addition to a number of tests and quizzes, a semester long research paper was assigned to the students: they were required to write a term paper on application of thermodynamic principles to an existing or emerging technology; topics included but not limited to seismic isolator, magnetic cooling, superconductivity and superfluidity, hydrogen powered vehicles, bio-fuels and photovoltaic cells.

After a thoroughly analysis of research paper reports, it was realized that the feedback from research paper reports were not as encouraging as envisioned because students didn't adequately link the theoretical principles they learned in the class to their research topics. In that regards, it was decided to replace the research paper with a computer simulation research project in which students simulate an energy changing process and analyze how energy change or transfer do happen and how theoretical knowledge they learned in the class do compare to the computer simulation results.

III. COMPUTER SIMULATION PROJECT

At the beginning of the semester, a computer simulation project to be accomplished during the semester was assigned to students. The project involved the use of COMSOL software that students have never used before.

COMSOL is a computer program that allows modeling and simulating a wide variety of physical phenomena in acoustics, electromagnetism, fluid dynamics and heat transfer, structural mechanics, chemical engineering, earth science, and microelectromechanical systems. COMSOL is an all-in-one geometry creator and mesher, solver and post -processor and is user-intuitive software. The fact that COMSOL is user-friendly made it easier for the students to learn the software.

The main challenge was to introduce students to finite element analysis and make sure they understand the simulation process i.e. steps involved during the simulation, 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 accustom them to COMSOL software: students were first divided in groups of two, mainly to facilitate collaboration (team work).Two tutorial examples, heat transfer through a solid cylinder and heat propagation during the breaking process, were then assigned to the groups (each group was assigned one of the tutorials); 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 tutorial each group was assigned: in the case of the heat transfer through a solid cylinder, students were asked to add a thin layer of a different material than the cylinder around the cylinder; in the case of heat transfer during the breaking process, students were asked to add a thin layer of a lubricant between the brake pad and the disk.

For both modified projects, each group was allotted a different material or lubricant

IV. PROJECTS REPORTS

The purpose of this project was two folds: learning computer simulation with the use of COMSOL software and technical report writing, the first being the main goal.

As the semester progressed, students' interest in computer simulation was visible and they started drafting the final report that 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.

Students who worked on the heat transfer inside the cylinder provided interesting assessment of their simulation results and it was encouraging to realize their growth.

Figure 1 shows the temperature profile of the cylinder subjected to a heat flux from the report of one of the students' group.

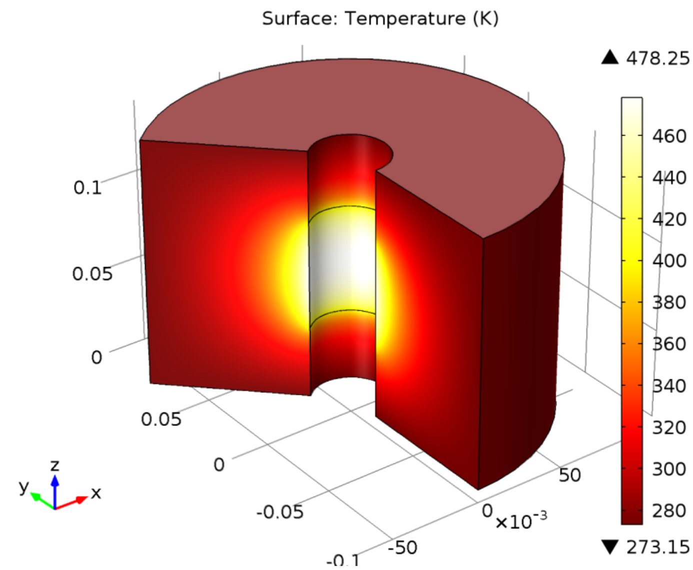


Figure 1: 3D Temperature of Cylinder without Coating

After the analysis, students had to compare the results to the case where a coating of a different material was added to the outside of the cylinder and show how the additional layer does affect the heat flux inside the cylinder. Figure 2 shows the temperature profile of the cylinder, from the same group, when a silicon glass coating was added to the outside of the cylinder.

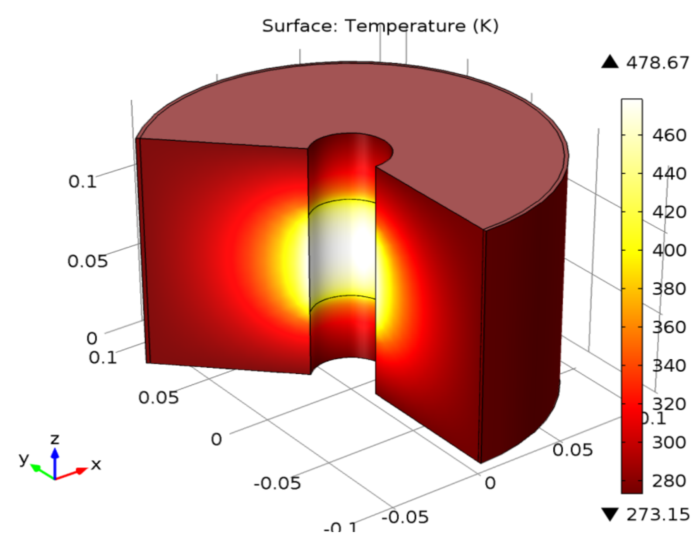


Figure 2: 3D Temperature of Cylinder with 2mm Silicon Glass Coating

In addition to the two above figures, students also provided a graphical comparison of the two cases to show how they compare to each other.

Figure 3 below shows the comparison between the two cases, one being the case of a cylinder subjected to heat flux, the other case being the same cylinder with an additional coating of a different material at the outside of the cylinder.

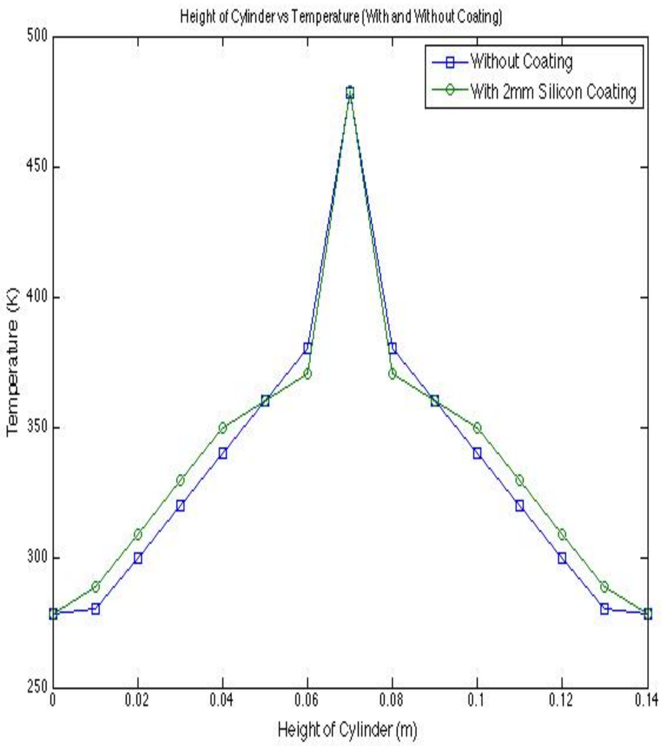
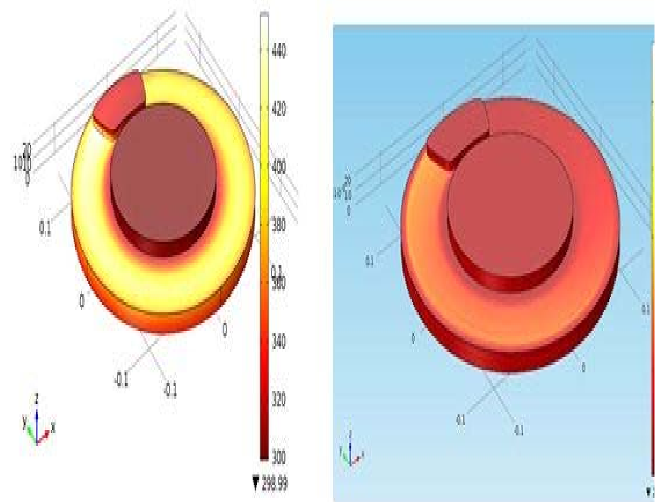


Figure 3: Graphical comparison of temperatures at different radial distances of the cylinder for both cases

It can be realized that Figure 3 shows an increase in temperature inside the cylinder when an additional layer was added to the outside.

In regards to students who worked on the heat transfer during the breaking process, their analysis also demonstrated a considerable progress also considering it was the first time they used any computer simulation software. Some figures and graphs extracted from one of the student's report reinforce the argument.

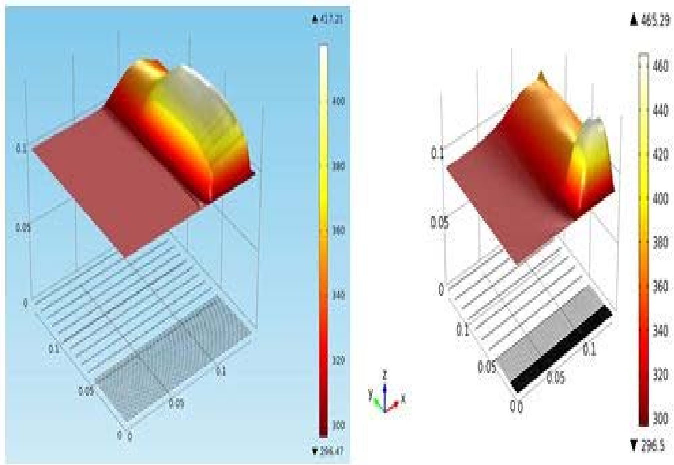
Figure 4 shows the temperature distribution in both the disk and the breaking pad for both the cases: the first case being the case of the breaking pad and the disk, and the second case was when a lubricant layer, 2mm of Polytetrafluoroethylene **(**PTFE), was added on top of the disk.



(a) **(b)**

Figure 4: 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 Figure 5, it can be realized that the maximum temperature is approximately 450K (Figure 5.a) and when a PTFE layer was added, the maximum temperature is approximately 420K (Figure 5.b).



(a) **(b)**

Figure 5: 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.

Overall students' satisfaction was verified using an anonymous 5 points scale survey, ranging from strongly agree to strongly disagree; the survey was administered towards the end of the semester. Students' responses as well as the questions they responded to are shown in Figure 6 below.

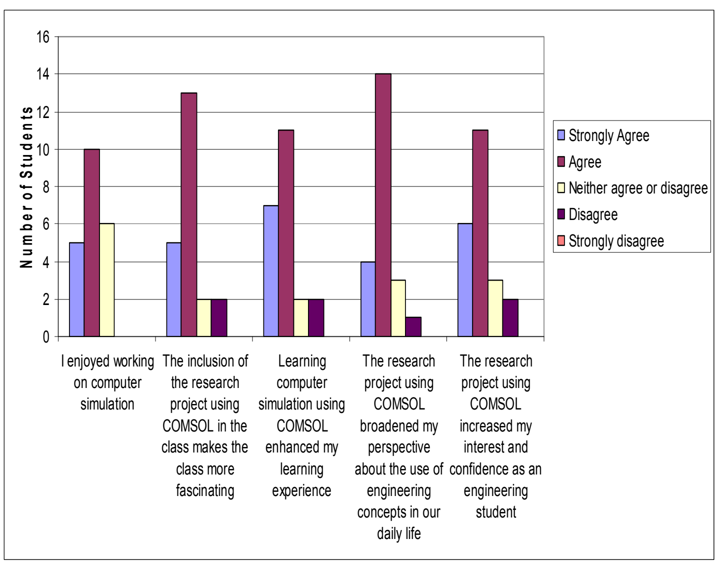


Figure 6: Students' survey feedback

As illustrated in the above chart, students responded positively to the inclusion of the computer simulation project in the course. We want to point out students' response to the first question:"I enjoyed working on computer simulation"; the mixed level of satisfaction, with a considerable number of students neither agreeing or disagreeing, can be attributed to the learning of new software coupled with the course load and time constraint.

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 our thermodynamics class, a computer simulation project was included in the class to help students not only learn about finite element analysis but also realize how theoretical knowledge they learn in the class translate to real life applications. Students worked on a simulation project using COMSOL software and produced a technical report to highlight what they learned during the process. Towards the end of the project, a survey was conducted to assess students' satisfaction in regards to the overall experience: a positive response to the questions they were asked reiterated how the projects enhanced their learning experience.

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