Project Based Learning Approach in the Heat Transfer Course for Undergraduate Students

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Abstract

Computer engineering courses often require knowledge from other fields, such as numerical methods and heat transfer. It is challenging to motivate students and show them how the contents presented in these units are connected to the core of their course. This paper presents a project based learning experience for third year undergraduate students of computer engineering at Insper Instituto de Ensino e Pesquisa. The students are required to work in teams to design a cooling system to a processor in a free version of the finite element software LISA. The theme of the project builds the bridge between heat transfer and computer engineering and the tool shows the importance of numerical methods in engineering. Teams are free to select any processor available in the market and choose fictitious parts, such as fans and fins, from a list provided by the instructor. Each item in the list is associated with a price, so they must propose and simulate numerous designs to optimize their final cost. Their designs are initially based on observation of the cooling systems available in computers and smartphones and then improved by their heat transfer knowledge. Students present their solutions to sell their designs in the end of the project. This experience could be adapted into a contest for the lowest cost if a single processor was provided to all groups. A contest can motivate the students, but may also worry them, while a free choice has been successful in making them active and keeping a light environment. This experience can be accomplished remotely without expensive software and create a bond between heat transfer, numerical methods and computer engineering.

Keywords: Project Based Learning; Heat Transfer; Numerical Methods; Engineering project.

1 Introduction

Many engineering courses have heat transfer and numerical methods units in their programme, but the importance of those units may not be clear to the students. For example, a computer or electrical engineering undergraduate may not see a straight connection between heat transfer and the core of their engineering courses. Also, the role of the engineer has changed lately and companies have been requiring their specialists to have a broader understanding of the projects (Santos, Ayres, & Miranda, 2018), not only regarding technical aspects but also about entrepreneurship, design thinking (Goldberg & Somerville, 2014) and soft skills (Kumar & Hsiao, 2007). Therefore, it is necessary to motivate engineering students to acquire knowledge from other fields.

Active learning (Christie & Graaf, 2017) strategies and project based learning (Kokotsaki, Menzies, & Wiggins, 2016) approaches have been widely used in engineering courses, especially to develop interdisciplinary tasks. The laboratory was transformed in an escape room game by (de la Flor, Calles, Espada, & Rodríguez, 2020), where chemical engineering students needed to answer heat transfer questions correctly to win. A sequence of tasks under the PBL methodology was designed by (Montero & González, 2009) to first year electronic engineering students, but their objectives did not include numerical methods. A PBL approach was suggested by (Zhuge & Mills, 2009) to motivate students to learn basic concepts of the finite element method. They focused on structural analysis and used a commercial software to develop their models. In this work, numerical methods and heat transfer are combined in a 1 week project under the PBL approach. Each team of students must select an existent processor, design a cooler by assembling parts from a list and use a finite element commercial software to simulate its performance.

This project was designed for third year computer engineering students, but the methodology can be applied to most engineering modules. Either as an introductory activity in courses that have heat transfer as a core unit (mechanical engineering, for example) or as a complementary assignment to other engineering curriculums.

This project does not require prior knowledge related to the finite element method or any commercial software, but students will have to analyse and discuss their results, therefore a reference containing such information has to be indicated.

2 Objectives and expectations

In this project, teams are free to select any processor and design the heat fins as they prefer. We expect this to enhance the engagement of the students in the project because they can choose a processor they have in their computers, mobile phones, videogame consoles, etc. Also, the solution space on heat fin designs is too wide, therefore teams that discuss more and work creatively tend to perform better in such an open-ended situation.

Many undergraduate engineering projects focus too much on the technical aspects and leave the cost out of the study. By including this aspect, we expect the students begin to consider the price of the components in their thoughts more often.

The main learning objectives of this project are:

- Research technical data of processor units
- Apply heat transfer knowledge (conduction and convection) in processor cooling systems
- Discuss and create potential configurations of coolers
- Solve heat transfer analyses in a finite element analysis software
- Understand concepts behind numerical solutions (finite element method)
- Eliminate and/or improve inefficient cooling systems based on heat transfer knowledge and simulation outputs
- Find a configuration that satisfies the maximum operation temperature of the processor
- Design a brochure with fundamental information on the final product

We expect this project to introduce the theoretical studies on conduction, convection and numerical methods. Depending on the course, it should be followed by a deeper study of the heat transfer governing equations and numerical methods algorithms.

3 Description of the activity

This project can be divided in four main stages: selecting a processor, assembling a cooling system from fictitious parts available in the store, using a finite element software to improve the system and presenting a brochure with the optimized configuration. The due date is within a week from publication of the assignment text.

3.1 Selecting a processor

Students are free to select any real processor, but their main technical data will be needed in the next stages of the project, therefore we encourage them to pick a processing unit whose specifications can be easily found. Most teams select AMD or Intel cores due to their popularity and availability of information, but a few students have explored smartphone processors and graphics processing units (GPU).

3.2 Assembling a cooling system

Instructors provide a list of fictitious parts and their respective cost (Table 1). Students can assemble their coolers by selecting a fan (if any), build a dissipator base to place heatfins on and assign one or more materials to their systems.

Table 1. Fictitious hardware store. Material properties retrieved from (Incropera, Dewitt, Bergman, & Lavine, 2007).

Price ($)	Hardware
30	Breeze fan ($h=30W/m^2K$)
60	Gust fan ($h=50W/m^2K$)
120	Cyclone fan ($h=80W/m^2K$)
5/heatfin	Heatfin manufacturing
$0.0005/mm^3$	Aluminum ($k=237W/mK$)
$0.02/mm^3$	Copper ($k=401W/mK$)

3.3 Using a finite element software

To quantify the performance of their coolers, students must model the assemblies in a finite element software. They are encouraged to use the free version of the LISA FEA software (Figure 1) (Sonnenhof Holdings, 2011), as it is an easy to learn tool and has enough resources to fulfil the objectives of this project. A video tutorial was provided by the instructors.

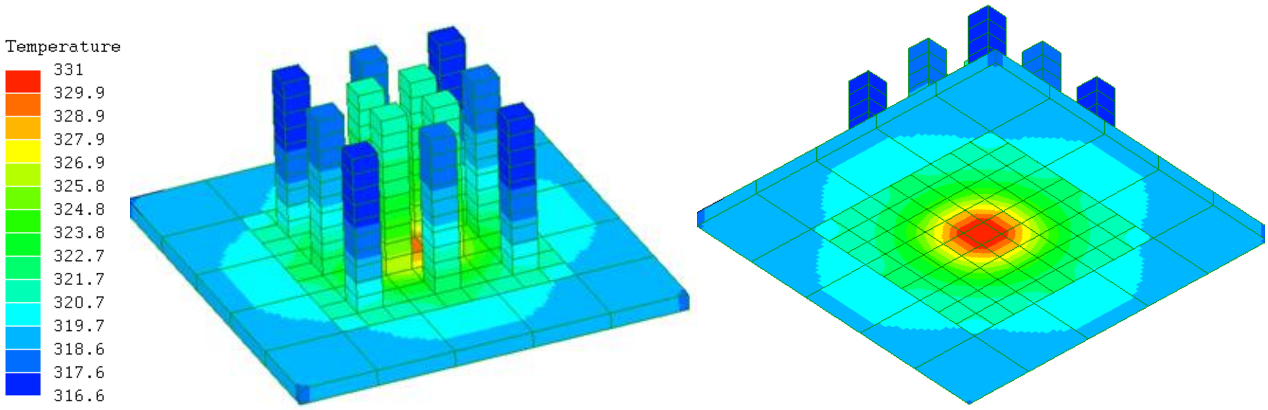

Figure 1. Example of a heat transfer analysis in the LISA FEA software of a cooling system. Temperatures in K.

There is a maximum limit of nodes in the free version of the software, which can be seen as an opportunity to create a sense of waste of resources. This limitation helps the students learn to refine their meshes around critical areas only, and not on the whole model.

The processor core is modelled as a heat flow rate on the bottom of the dissipator. Its Thermal Design Power (TDP) and dimensions depend on which processor was chosen by the team. The design of the dissipator base and fins are free, but the materials must be listed in the store. The exposed portion of the base is subject to free convection, while the fins are subject to forced convection, whose coefficient h depends on the fan the team has selected from the list. They can also decide to not use any fan (which is mandatory for mobile processors, for example), in this case, fins are also subject to free convection. The main technical objective is to keep the highest temperature below the maximum operating temperature of the processor while minimizing the total cost of the system. Therefore, a solid discussion and a few trial-and-error iterations are required to obtain an improved solution.

3.4 Presenting a brochure

After analysing potential cooling systems, deciding on a better configuration and optimizing it, each team must create a brochure and pitch their cooler to the teachers. The brochure has to contain the processor's name, TDP and junction temperature, simulation parameters and outputs, final cost and all relevant information about the cooling system.

3.5 Assessment rubrics

To make the grading process more objective and accurate, a few topics are assessed and the grades are calculated under the rubrics **Invalid source specified.** presented in Table 2. The main topics to be assessed are:

1. Brochure: showed technical data of the selected processor unit
2. Brochure: showed a finite element analysis (graph/figure) of their design
3. Brochure: satisfied the maximum operation temperature of the processor
4. Pitch: mentioned previous configurations of coolers
5. Pitch: discussed heat transfer processes and their importance on the design

Table 2. Assessment rubrics.

Incomplete (0%)	Developing (25%)	Essential (50%)	Proficient (75%)	Distinction (100%)
Items 1 or 2 are incomplete.	Cleared only items 1 and 2.	Cleared only items 1, 2 and 3.	Cleared only items 1, 2, 3 and 4.	Cleared all items.

4 Student submissions

This section contains two examples of student submissions we found to be interesting. In the first example (Figure 1), all mandatory information is present in the brochure and the team managed to keep the highest temperature within the limit specified by the manufacturer. Even though their design could have been further optimized, e.g. removing cold spots from the external fins to save material, it is safe to state that the requirements of the assignment have been attended. Contrarily, the second example (Figure 2) lacks the final cost of the system, also their fins are poorly distributed as the hottest region of the dissipator does not have a fin and the fins on the corners are cold. This kind of submission suggests the team knows how to operate the software and understood the main objectives, but their learning experience would benefit from a richer discussion and more trials.

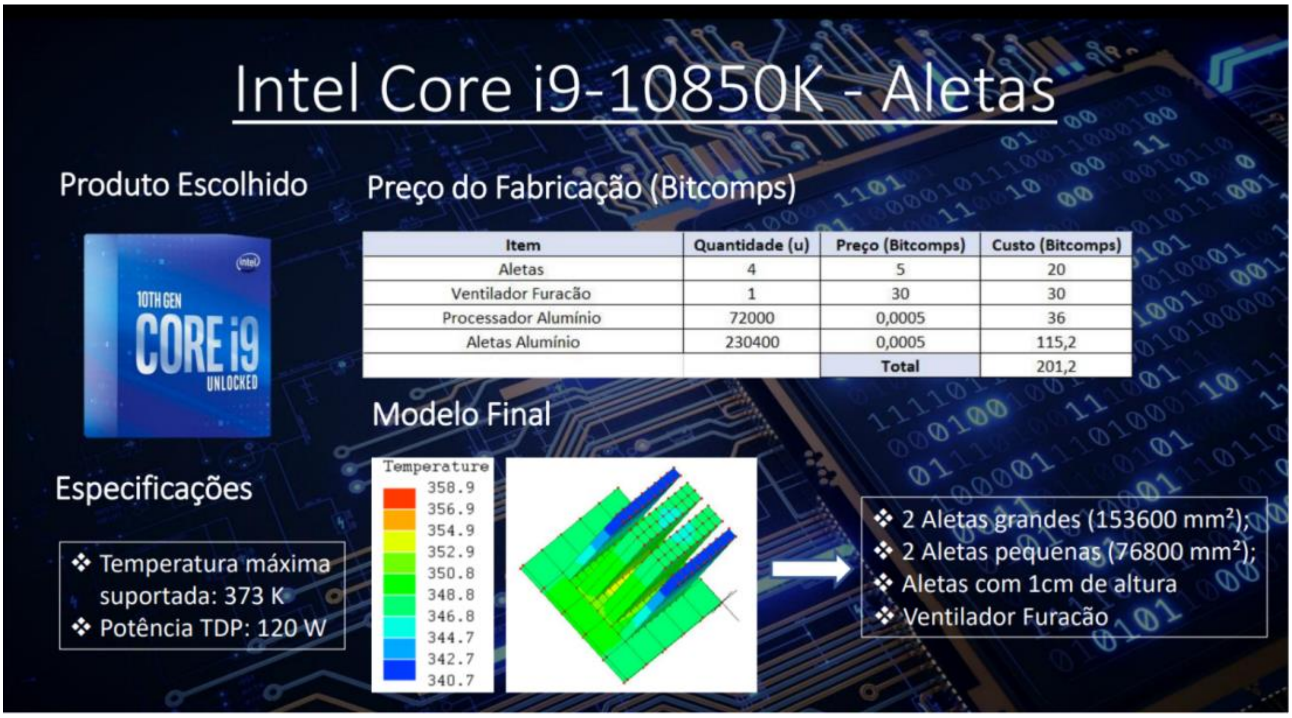

Figure 2. Student submission 1.

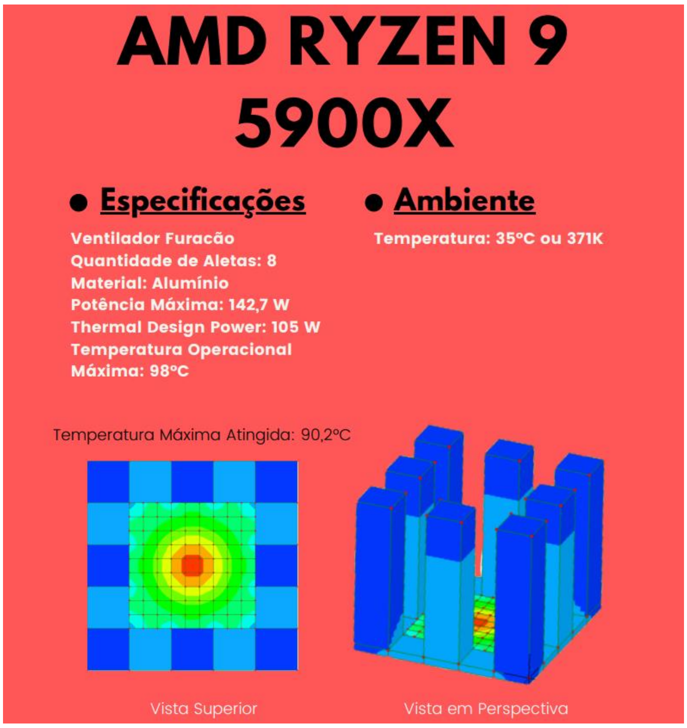

Figure 3. Student submission 2.

5 Performance of the students

Only 50% of the teams presented a brochure in the end, the other groups organized the results in different formats. The proposal of using a brochure to advertise their coolers must be reinforced in a future iteration of this project. Additionally, during the group discussions, a few students wanted to explore different processor units but did not manage to convince their partners. If the teams had been divided according to processor preference, maybe more diversity of coolers would have appeared. Only one team chose a mobile Snapdragon processor while all other groups selected regular CPU from Intel or AMD.

However, all teams developed cooling systems that satisfied the maximum temperature allowed by the manufacturer, which indicates they understood the basic objective of the project and all of them obtained at least a 5/10 grade. Around 30% of the teams truly dived in the problem, presented fine results and obtained a maximum 10/10 grade.

6 Teachers' perception

The first designs of the students were mostly based on observation of coolers and slight improves on the tutorial we provided. But many groups managed to discuss and provide better results based on heat transfer knowledge. The activity can run remotely or in person as long as the teachers can enter the group discussions to hear and eventually steer the conversation into fruitful topics. Also, each team has access to at least one computer. We found it may become too demanding for a single teacher to interact at a personal level with the teams if there are more than 20 students in the class, it is ideal to have at least two instructors to follow the group talks in that case.

If all teams were forced to use the same processor, this project could be transformed in a contest where the team with the lowest price cooler (that satisfies the maximum temperature) would win. The competition would favour the optimization step and could extrinsically motivate a few groups, therefore it is worthy being considered, but we felt most of the students were already intrinsically motivated by the free choice of processor. The non-competitive atmosphere foments cooperation between groups, which enhances the learning experience. Additionally, in a scenario where all groups have the same processor, plagiarism would become a concern for the teachers and among teams.

7 Conclusion

An open-ended PBL activity on heat transfer and numerical methods has been presented. The experience was executed on a computer engineering class at Insper Instituto de Ensino e Pesquisa, but any undergraduate engineering course can run this project. Students worked in teams to develop a processor cooler using parts from a fictitious store and a finite element software. The final handout was a brochure containing information about their designs, two student submissions were presented as examples. The first example may not be optimal, but it surely had been improved to a certain extent and attends the expectations. The second example indicates the team could have discussed better and tried more configurations to show a more efficient cooler. A table for assessment rubrics is presented to increase the accuracy and objectivity of the grading process. Future steps involve reinforcing to the students the value of the brochure format, applying the project methodology on students from other engineering modules and running a questionnaire to accurately assess the students' perception. From personal interaction with the teams, the project was well accepted by most of the students, who understood the importance of heat transfer concepts, teamwork and numerical methods to engineers of all fields.

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