Introducing TCAD tools in a Graduate Level Device Physics Course

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Abstract

We have introduced Synopsys TCAD tools to students taking our core graduate course in device physics. Learning these tools was a key component of their class project. Students learned the tools in our new lab (donated by Synopsys and Intel through a Synopsys’ Charles Babbage Grant) using Synopsys’ and complementary tutorials developed in-house. Through analysis of student performance and project characteristics, we found that project complexity seemed to have negatively impacted students’ academic performance. In this paper, we will present lessons learned introducing a TCAD tools.

1. Introduction

We introduce TCAD (Technical Computer Aided Design) to the students taking our core course in semiconductor physics in the EE department of San Jose State University. This course is a prerequisite to all of our graduate full custom analog and digital circuit design courses, as well as a follow-up to courses in device physics and semiconductor processing.

We recognize that introducing TCAD tools to our first year graduate students is an important yet difficult task [1,2]. For instance, professors need to know the TCAD tools thoroughly to be able to answer students’ questions. For their part, students need to be competent in areas such as grid generation, numerical methods, and device physics to be able to successfully model and design a device. Students also need ample and well-maintained computer resources to run the TCAD tools.

This paper describes the details of our device physics course—including, how we introduced Synopsys’ TCAD tools to our first year graduate students, and how we addressed the teaching/learning problems associated with using TCAD tools. Regarding student learning, we use Cognitive Load Theory [3] to explain why students who attempted projects that were too complex earned a significantly lower course grade than students who chose less complex projects.

2. Course Details

EE221 Principles of Device Physics is a required course in our MSEE program. Two key learning objectives in this course are: students will explain and extract device circuit parameters, including threshold voltage, junction capacitance, ideality factor, and series resistance; and, students will describe how a CMOS process is designed and sequenced. To better support these learning objectives, we introduced TCAD tools in an open laboratory environment [3].

For this course, students learn the tools in class from demonstrations by the instructor, and by following tutorials provided by Synopsys [4] or developed in-house [5] assigned for homework. Class meetings are held in our Linux Laboratory Donated by Synopsys and Intel though a Charles Babbage Grant.

Once students learn how to run a simple diode and NMOS (N-type Metal Oxide Semiconductor) processing and extraction example, they select their partner (maximum group size is 2) and their group project. Projects ranged from Solar Cells (simple) to GaN HEMT structures (very complex). As part of the instruction, there are three design reviews throughout the semester, including a one-on-one discussion of the group’s literature review.

3. Student Learning

By the end of the semester, we noticed that students who were attempted more complex projects, such as LDMOS (Laterally Diffused Metal Oxide Semiconductor) or HEMT (High Electron Mobility Transistor) structures, showed less skill attainment than other students who chose simpler projects. To test our conjectures, grades for the 40 students in the course were aggregated into four groups based on the complexity of their project. Group 1 projects consisted of modeling and designing Solar Cells and MOS capacitors; group 2 projects consisted of modifying the Synopsys NMOS example; group 3 projects consisted of process modeling and electrical simulation of our in-house NMOS processes; and group 4 projects consisted of modeling LDMOS and HEMT structures. Group means for project grade, final exam, and final course grade were then plotted by group/project complexity (Fig. 1).

As can be seen in Fig. 1, the means for students in the complex projects (Group 4) was significantly lower than the mean for the other groups. Students in group 4 had a final...
course grade average of 79% (C+), as opposed to the other groups which had an average final grade of 88% (B+). The students in group 4 scored much lower on both the project and final exam.

These findings suggest that students who chose the most complex projects did not learn as much as those who chose the less complex projects. Findings also suggest that for the students in group 4 the TCAD tools hindered, rather than facilitated, learning. Such findings have major implications given that teaching TCAD is very resource intensive. Thus, it is important to understand why the drop in student learning, as shown by grades, had occurred. Cognitive Load Theory can be used to explain these results.

Cognitive Load Theory (CLT) models the human mind as an information processing system with limited resources. One of these limited resources is called working memory, which basically implies that a person can concentrate only on a limited number of concepts at a time before the mind becomes overloaded. A mind that is overloaded has major difficulties processing information or learning new concepts. Since learning TCAD involves many new concepts (UNIX, device physics, meshing, processing), this activity tends to overload students’ mind. It also seems that attempting to model the advanced devices (with extra concepts such as LDMOS, or quantum based structures) is overwhelming students’ cognitive capabilities and negatively impacting their learning.

If learning TCAD tools is likely to cause cognitive overload in students, then why did the other students perform well in the class? Based on our observations, we believe that students in the less complex projects made better use of their cognitive resources by selecting a project that will provide the most efficient use of their ‘cognitive capabilities,’ or the best alignment between cognitive resources and load.

Another explanation for the better performance of the students in the less complex groups relates to the resources available to these students to better manage the cognitive demands of the tasks. Students in groups 1 to 3 were able to take advantage of a tutorial we developed, which shows step-by-step how to design the process of a diode (sprocess), re-mesh it for electrical simulation (Sentaurus structure editor), simulate the diode electrically (sdevice), and extract the ideality factor (inspect). The tutorial also had extensive help/documentation about our in-house NMOS processes. This in-house tutorial was quite detailed and had a visual for each step (over 100 figures), which we believe reduced students’ cognitive load and produce better learning. The advanced/complex device group had no such example files.

4 Conclusions

Learning TCAD tools can be an excellent way to teach semiconductor device physics and processing. In order to be successful, the instructor needs to address issues such as students’ cognitive load, which may include the use of detailed tutorials and case studies. We also found that projects that are too complex for a basic graduate course in device physics should be avoided.

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REFERENCES