TEACHING AND LEARNING THE FINITE-ELEMENT METHOD - EXPERIENCES WITH A DIVERSE GRADUATE STUDENT BODY

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The paper reports on aspects of teaching the finite element method (FEM) to power engineering graduate students with different backgrounds, research interests, and professional ambitions at the University of Wisconsin-Madison (USA). The activities described aim to strengthen the ability of the students to discern and identify the important parameters for use of FEM, the students' perceptions of the advantages and limits of numerical simulation tools and their reasonable use, and the need for selective analytical verification. The discussion is extended to include experiences obtained at the Institute of Electrical Machines (IEM) at RWTH Aachen University. Thereby, the paper seeks to help identify teaching methodologies and best practice for given settings and purposes.

CHANGING UNDERSTANDING OF EFFECTIVE ENGINEERING EDUCATION

Different issues in engineering education have been a topic of discussion for several years. Large driving forces are the rapidly evolving engineering field and an increasing understanding of how students learn best [1, 2]. This has been emphasized by ABET-mandates and ABET- and NSF-reports [3, 4]. The merging of the disciplines has been emphasized, including the need to develop long-lasting skills that can be applied to new situations, particularly non-technical skills ("soft skills"). These developments have to be taken into account without simply extending the curriculum in a way that would increase the students' load.

Simultaneously, educational literature has pointed out that there is often a mismatch between a traditional way in which instructors teach and how students learn. Felder and others [5–8] have suggested that understanding of the different learning styles of students and their classification, such as given by Felder-Silverman [5], Myers-Bridge [6], and Kolb [8], can provide a helpful framework to increase the efficiency of instruction and to better meet the needs of the different categories at least part of the time.

Following these calls, methods that motivate students to learn on their own and retain knowledge, that provide a deeper understanding of fundamental principles by developing methods for observing and/or experiencing them in action, and that engage the students in a variety of ways to avoid forcing them to just listen and take notes have become more important. Here, the instructor is less of a "talking" head and more of a facilitator of learning.

CONTEXT: A GRADUATE COURSE ON AC MACHINE DESIGN

The context is a graduate course on ac machine design[1] at the University of Wisconsin-Madison. The course objective is to provide the basic principles for the electromechanical design of ac machines, enabling students to perform basic design studies for their applications. Topics include magnetic circuit concepts, calculation of equivalent circuit parameters from geometric data, copper and iron loss calculations, and theory and application of finite elements to electromagnetic devices. All enrolling students have had an introductory course in electric machines. Except for this, the student body is very diverse, ranging from newly arrived graduate students with hardly no machine experience to PhD students who are conducting research on machine design.

The integration of FEM work was part of a revision of the course content and teaching methodology which was caused by a change of the instructor. To account for the importance of understanding the delivered material through application, 65% of the final grade are determined by two design projects. With designing being an iterative process, the project work both increases understanding of the correlations of the different parameters and enhances familiarity with the various aspects of the complex process. The first project (25% out of 65%) consists of an analytical electromagnetic design of an induction machine,[2] the second (40% out of 65%) of a more comprehensive design of a permanent magnet machine. Here, the main magnetic circuit of a three-phase permanent magnet motor is designed analytically and verified numerically. The equivalent circuit and the loss balance are derived from the magnetic circuit.

Acquisition of the required working knowledge on FEM is part of the project (See the extract of the assignment shown in Fig. 1).[3] The students investigate and decide by themselves how to approach the problem by consulting with their peers, the instructor, and drawing from other sources. With respect to the lecture part of the course, only two 75 min lectures are assigned to the FEM topic. Here, an introduction into FEM theory and different steps of FE analysis are given. In this format, student learning by their own exploration of the unknown ground is enhanced. At the same time, non-necessary time and energy expenditures that often come along with "learning something the hard way" are avoided via the "remote" supervision by the instructor.

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[1] ECE 713 "Electromagnetic Design of AC Machines"

[2] Non-linear behavior included

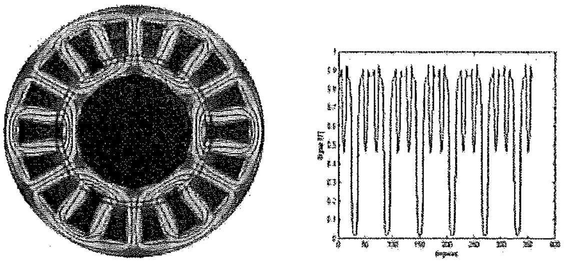
[3] The software is made available via the University's Computer Aided Engineering Center.

1. Implement the magnetic equivalent circuit of a permanent-magnet motor as described above into a computer software program. In the following, this tool will be referred to as "design tool."
2. Verify your design tool with one of the available 2D finite element packages.
3. Extend your design tool to include...

Figure 1: Beginning of the assignment.

RESULTS

Completed assignments: All students mastered this part of the project very well. The assignment intentionally only vaguely describes how the analytical results shall be verified numerically. Thereby, the students are not restricted to one way, but can decide on "good" verification by themselves, and are encouraged to explore techniques that exceed the minimum required.[4] In addition, a high burden being placed on the younger students is avoided. The range of answers is illustrated by two examples, both coming from students with no prior FE experience but who are 3 years apart in school (Figs. 2 and 3 and 4).



(a) Cross sectional area. (b) Air gap.

Figure 2: Example of numerically calculated flux density distribution.

"Fig. 2 shows the air gap flux density in the machine. The figure is obtained by post-processing in.... The mean of the flux density is calculated to be 0.62T. The initial flux gap density used in the design tool was 0.66T. The machine is modeled with open slots what explains the irregular shape of the air gap flux density."

Figure 3: Example of short discussion of the numerical results.

"The FE-analysis was performed for rated conditions with the machine carrying rated current that was aligned with the magnet q-axis. This situation should give us the rated torque of the machine... FEA-Mesh... B-Field... Flux-Lines... Inductance Comparison:...The slight discrepancy in the inductance is due to the fact the FEA drawing of the conductor in the slot does not match exactly with the parameters used for theoretical calculation.... Torque Production..."

Figure 4: Example of extended discussion of the numerical results

Most "older" students elaborated on the question to a similar extent as shown in Fig. 4, without being required to do so but being driven by their own motivation.

Learning outcomes: Judging from interviews conducted with the students six months after the end of the project, the learning objectives stated above were achieved to a satisfying extent. All students can explain how to discern and identify the important parameters, are aware how powerful but also time consuming numerical tools can be, and know that these tools cannot replace understanding and analytical approaches but need to be used with reason to exploit best the possibilities offered.[5]

Related experiences: The described findings are well in line with experiences obtained at IEM with students before and after completing the Dipl.-Ing. degree. Here, the students work on FEM-related projects in the form of a study or one of their final projects. Here, the learning is also mostly driven by the students' own exploration under the guidance of members of the institute.

CONCLUSIONS

This paper gives a short overview of experiences with teaching the FEM to a diverse graduate student body at UW-Madison (USA) and IEM/RWTH Aachen University (Germany). By describing the approach it is illustrated how important learning outcomes can be achieved.

References

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[4] The setting allows that the project is graded as a whole and no sub-points/-weights are defined.

[5] At the time of writing, the course is delivered as outreach course to off-campus students all over the US, using prerecorded lectures. Experience drawn from this context will be available in Spring 2006.