Reinforcing learning in engineering education by alternating between theory, simulation and experiments

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Abstract

Traditional engineering education has relied on teaching theoretical fundamentals, reinforced in some courses by laboratory experiments. However, for practical reasons experiments are limited in the scope, and many students fail to make the necessary connections between the theory and its applications.

To bridge the gap between theory and applications we use the tools of Computer Aided Engineering (CAE). The hands-on use of simulation tools such as CAD, FEA or Motion Analysis helps students visualize and understand the application of theory to real engineering problems and allows students to model and simulate much more complex problems than are amenable to hand calculations.

At the same time, the use of commercial simulation software provides students with skills that are in high demand in the market place.

1 Introduction

The last decade has brought tremendous progress in Computer Aided Engineering (CAE) tools in disciplines such as Computer Aided Design (CAD), Finite Element Analysis (FEA), Motion Analysis, and Computational Fluid Dynamics (CFD). These CAE tools have matured enough to become productivity tools for practicing engineers. By using CAE applications, engineers are able to shorten the design process by replacing physical prototyping and testing with simulation.

Employers expect our graduates to have working knowledge of CAE applications. Therefore, our responsibility as educators at Western Engineering is to equip our students with understanding of engineering principles along with working skills in the CAE tools.

How can this be done considering an already very busy engineering curriculum? How can we possibly teach the use of CAE software without running the risk of turning courses into software training where understanding of the method takes only a secondary role?

2 Climbing two ropes method

To accomplish the task of teaching students theoretical background and providing them with skills in commercial CAE programs such as FEA while working under severe time constraints (one semester), we alternate between theory and numerical simulations of the corresponding problems. Once students acquire the working knowledge of software we use the numerical simulation to solve problems way beyond the reach of hand calculations. This, in turn, enhances the grasp of theory. This approach may be descriptively called the "Climbing Two Ropes" method or C2R (figure 1).

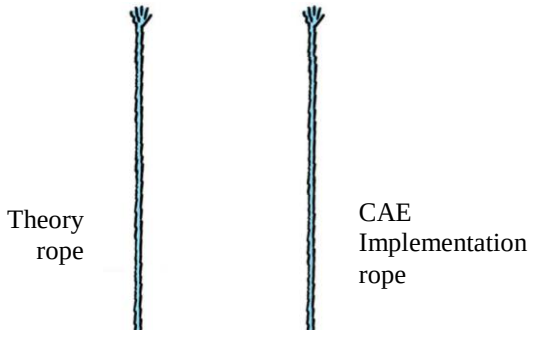


Figure 1. The essence of the C2R method is a well timed switching between theory and CAE implementation

2.1 Description of the method

We explain the method using the third year course "Finite Element Methods for Mechanical Engineering" as an example. The course starts on the implementation rope. Students use the commercial software COSMOSWorks to study the modeling process, necessary simplifying assumptions, discretization error, convergence and basic modeling techniques. When we switch to the theory rope to analyze 1D spring elements, students are already sufficiently advanced on the implementation rope to model 1D spring elements with COSMOSWorks. While confirming hand calculations with software results students come to appreciate restrictive assumptions of 1D spring elements and develop skills in modeling techniques required to simulate them in a 3D model. This deepens the understanding of theory behind 1D spring elements and further develops software modeling skills (figure 2).

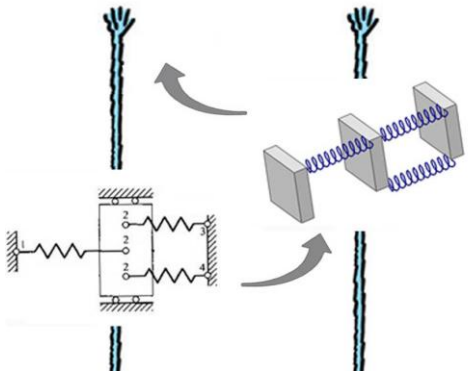


Figure 2. 1D spring elements on the theory rope are simulated on the implementation rope with a COSMOSWorks model

One week later we return to the theory rope to tackle 2D truss elements. They are still simple enough to allow for manual calculation, yet they are illustrative because all concepts that apply to 2D truss elements are fully expandable to "real life" elements used in commercial software. We introduce the theory of 2D trusses and again we simulate them with commercial software using models of different levels of idealization (figure 3).

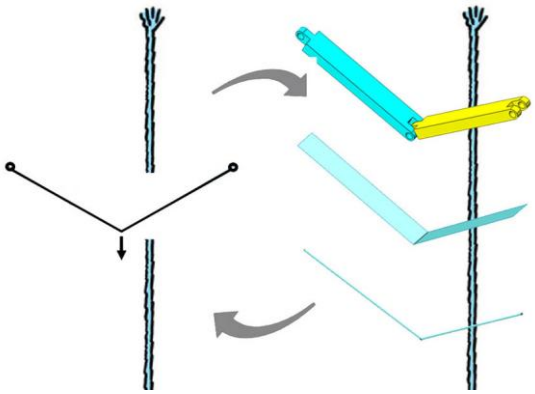
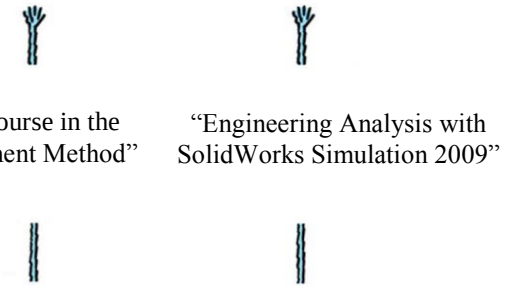


Figure 3. 2D truss elements on the theory rope are simulated on the implementation rope with commercial software using models of different levels of idealization: solid elements (top), shell elements (middle) and beam elements (bottom).

Climbing on both ropes continues until the end of the semester, to allow students develop FEA skills ready for practical implementation as well as good understanding of the underlying theory.

The course taught with the C2R method is not just a common mixture of theory and applications. Carefully measured time intervals spent on each rope produce a synergic effect benefiting both ropes. Learning is further enhanced by textbooks used on each rope (figure 4) [1], [2].



"A first course in the Finite Element Method"

"Engineering Analysis with SolidWorks Simulation 2009"

Figure 3 The textbook on the theory rope is a popular introductory FEA text book [3]. The textbook on the implementation rope focuses on the applied FEA [4].

2.2 Course prerequisites

Successful implementation of the C2R method to the third year course "Finite Element Methods for Mechanical Engineering" requires that students be familiar with CAD. This is because modern FEA software is so tightly integrated with CAD that FEA users must be familiar with CAD to be able to use the FEA.

Western Engineering students are first introduced to CAD in the first year course "Introductory Design and Innovation Studio". Second year Mechanical and Materials Engineering students further develop CAD skills in the course "Product Design and Development". This course introduces students to a structured design process from inception to prototyping. CAD is one of many tools used in the design process and we can't spend too much time on it. Therefore, students acquire CAD skills not in class but by working on design projects that require the use of certain modeling techniques. We run the course in close collaboration with University Machine Services (UMS). Members of UMS participate in lectures and labs to assure that product documentation (including CAD models) meet industrial standards. To promote development of CAD skills, a bonus is offered for passing the SolidWorks certification exam. The SolidWorks Corporation offers the exam to our students for free. In the Fall 2008, over 50% of the MME2259a class (45 students) passed the certification exam!

"Product Design and Development" is a prerequisite to "Finite Element Methods for Mechanical Engineering".

2.3 Evaluation of the effectiveness

To this date we have used the C2R method to teach "Kinematics and Dynamics of Machines", "Finite Element Methods for Mechanical Engineering", "Finite Element Analysis for Design Engineers" and "Mechanical Vibration". All together there were ten courses run with this method. All scored over 6 (out of 7) for effectiveness on students' evaluations.

Another way to evaluate the effectiveness is to monitor students' performance in the fourth year, mainly in the 4th year design project. In fact, this year we have been approached by many students working on the 4th year design project. They were all successfully implementing the Simulation in the design process.

Yet another way to evaluate the effectiveness is to assess the performance of students in the Industrial Internship Program (IIP) in which some of our students enroll after completing 3rd year. Given a limited sample size it is difficult to generalize but we did notice several individuals successfully implementing both the theory and CAE tools to solving real life design problems with the skills level normally expected for an engineer with a few years of experience.

2.4 Applicability of the C2R method

The C2R is applicable to any course where theory intertwines with implementation problems suitable for the CAE tools. One could visualize common assignments or the same problems passed form one course to another for different treatments according to course discipline and objectives. This initiative is now in progress at Western Engineering.

2.5 Software used

The design curriculum in the MME department has been standardized on SolidWorks CAD. SolidWorks is a solid, parametric, feature based program, one of the most common CAD programs in industry. The C2R method has been developed around SolidWorks and its add-ins such as COSMOSWorks and COMOSMotion Are the acquired skills software-specific? To some extent they are, but since SolidWorks and its add-ins feature state-of-the art technology, these skills are easily transferable to other CAE applications.

3 Next steps

The next phase is to extend the approach to include physical experiments. Simulations are very useful, but they are only an approximation of reality. Simulation results must be verified experimentally, and students must understand the limitations and implications of modeling assumptions and simplifications. We propose to achieve this by introducing simple experiments to supplement theory and simulations. This would correspond to adding the third rope: experiments, and converting where applicable, the M2R method into a M3R method. For example, a spring-mass-damper system could be analyzed theoretically, modeled and simulated using CAE, and finally experimentally tested. This has already been implemented in the fourth year elective course

"Mechanical Vibration" and our efforts are underway to include other courses.

References

[1] D.L. Logan, A First course in the Finite Element Method, Brooks/Cole

[2] P.M. Kurowski, Engineering Analysis with SolidWorks Simulation 2009, Schroff Development Corporation