2006-1833: COMPUTER AIDED ENGINEERING - INTRODUCTION IN A MULTI-DISCIPLINARY ENGINEERING PROGRAM

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Computer-Aided-Engineering:
Introduction in a Multi-disciplinary Engineering Program

Introduction

Computer-aided engineering (CAE) and computer-aided design (CAD) are taking an increasing role for the practicing engineer in both design and analysis context. For the practicing engineer, it provides an opportunity to explore creative ideas without the initial expense of prototypes and/or pilot facilities. The importance of CAE in engineering education is well established and many engineering programs now include some type of formal education utilizing solid modelling software packages[1,2,3]. Many studies have shown that the use of CAE software enhances the learning of students at all levels from first year[4,5,6] to fourth year[7,8]. The CAD/CAE software packages themselves tend to be broad based, offer extensive tools for the experienced practitioner and hence they may not be intuitive to the novice user.

CAE is not a trivial domain. It is easy to generate results that are incorrect and dangerous[9]. Therefore, it is essential to know what is going on within a software program and recognize the software's limitations[10]. Unfortunately, it is easy for a student or the practitioner to generate impressive pictures with CAE software which display completely erroneous results. Engineering education must develop strategies to ensure that our graduates recognize the power of CAE while respecting the risks and responsibilities associated with its use.

The University of Guelph offers fully accredited engineering programs in Biological, Systems and Computing, Environmental, and Water Resources. Each program at Guelph is multidisciplinary blend of traditional engineering disciplines. Design is recognized as the essence of engineering and has been delivered at the School through a core sequence of design courses since the early 1970s[11]. These core design courses offer all of our students the experience of working in multi-disciplinary teams. The introduction of CAD/CAE tools into the curriculum began in Fall 2000 with a single course and has evolved to be offered in three second year courses. This paper presents the current approach, which has largely been in practice for the past 2 or 3 years. The paper then discusses some of the key attributes that are believed to be important for success and assesses the level of intelligent usage by students in their fourth year capstone design projects.

CAD/CAE Delivery in Second Year

The participating second year courses are Engineering & Design II and Material Science (fall offerings), and Fluid Mechanics (winter offering). All of these courses are taken by all engineering students at Guelph. Solid modelling is introduced in Engineering and Design II. The basics of finite element modelling related to solid mechanics problems are introduced in Material Science. Computational fluid dynamics is introduced in Fluid Mechanics.

Engineering & Design II is the core course supporting CAE. The students, in teams of approximately 10, start in the machine shop dissecting a product. Over the years, the products have ranged from refrigerators, to computers, to the components of a 1986 Honda Prelude. This exercise provides the students with hands-on experience. In addition, the exercise helps to reinforce the fact that their computer work must ultimately be grounded in real engineering products. The result is that each student leaves the shop with one or more individual parts from their team's product and thus an individualized assignment. They spend the next several weeks individually recreating their part(s) within a solid modelling software package. Assessment of a student's 3D results is based on a combination of visual comparison of the computer version relative to the actual part coupled with a comparison of the computer calculated mass (requires the students to correctly identify the material of their part) with the actual mass of the part. The final grade assigned does factor in an assessment of the degree of difficulty to recognize the variability in the student's assigned parts. High quality work is also rewarded through an assembly bonus. For this bonus, all of the members of a product's team are encouraged to electronically reassemble the product from the individual parts.

Material Science provides the introduction to finite element analysis (FEA) as it relates to solid mechanics. The student's task is to complete a basic FEA on one of the individual parts they received from the Engineering & Design II exercise. They are encouraged to conduct the FEA with a simple version of their solid model and to select reasonable boundary conditions and material properties for their part. They are required to demonstrate model convergence and to assess whether their FEA model results are reasonable by conducting simplified hand calculations.

Fluid Mechanics provides the introduction to finite element analysis as applied to computational fluid dynamics (CFD). The theme of individualized assignments is extended into this course; however, it is not based on their parts from Engineering & Design II. Each year, the students have been collectively assigned a flow element. The elements have ranged from pipe elbows, to a rapid expansion to a venturi flowmeter. The assignment becomes individualized by providing each student with different values for dimensions, fluids and flowrates. A parameterized part is provided to the students to permit the students to focus on the CFD questions and issues. The students are challenged to conduct the CFD analysis, assess model convergence and interpret the final results. In some cases, the result is to be compared against literature published results (e.g. the loss coefficient for a pipe elbow) and in other cases the comparison is to experimental results from the lab component of the course (ie. Venturi flowmeter).

In all three courses, the student's learning is supported by faculty, support staff, graduate teaching assistants and peer-based, collaborative learning. Stiver *et al.* provides further insights on the efforts to promote collaborative learning[12]. A number of on-line tutorials have been created to complement the tutorials provided with the software.

Assessment Methodology

The CAE/CAD introduction in second year is hoped to spur increased usage of CAD/CAE and development of innovative designs among our students in their capstone design projects and ultimately as alumni. Is the introduction in second year working? Are our senior students and alumni using CAD/CAE intelligently or are they using it as a black box? We opted to use recent capstone design projects to provide some initial feedback. These projects have been conducted by students who have experienced our second year courses.

Capstone design projects at Guelph are identified and developed by the students and completed in a single semester. Teams are typically made up of 3-4 students. Actual product development, prototyping and industrial collaborations are encouraged. Each design team has a faculty advisor but they are encouraged and free to seek help from all faculty in the school.

To quantify whether CAD/CAE is being used intelligently we asked University of Gueph Professor Emeritus Jan Jofriet to review four capstone design reports (which incorporated CAE as part of the design process) against a number of 'intelligent use' indicators. Professor Jofriet has an extensive background in researching and teaching of FEA. The projects utilized either CFD or solid mechanics within their design. Six measures were used to assess the level of intelligent CAE use. Table 1 provides the six measures and the descriptors used for each of these measures.

Observations and Discussion

One of the most valuable outcomes that has resulted from this effort in the second year curriculum is the increased dialogue that has occurred between the course instructors. In addition, the students see increased connections between the courses they are taking. As just one example, students are routinely asking their Material Science instructors for assistance in identifying the materials of their assigned parts for their design class.

We opted to use a single software platform capable of conducting solid modelling, solid mechanics and CFD. This was done to minimize the learning curve of the students in the three second year classes.

In the early and naïve offerings, individualized assignments were not created. For Engineering and Design II, in the first year only eight different items were used for the entire class. It was quite clear that not all of the submissions were individually generated. Adding the dissection component provided an efficient mechanism to create individualized assignments. After a couple of years of individualized parts for Engineering & Design II, we began using these same parts for the solid mechanics project. This strengthened the link between the courses and provided individualized assigned for the Material Science course. Individualized assignments are now seen as one important strategy in the success of this initiative. They lead to students taking individual ownership for their work and leads to individual accountability.

Individualized assignments change the preparation requirements for all of the instructors. It is not possible for each instructor to have prepared specifically for each student's particular challenges. It quickly became clear that all instructors needed to provide a higher level support and that additional resources were needed to support the students. Higher level support meant acting as a coach to help the students discover the solutions themselves. Two key additional resources have been developed. A peer-based collaboration system established that permits and rewards students for helping each other out. Lastly additional on-line tutorials have been created. These tutorials have been necessary and useful to bridge the gap between second year engineering student's knowledge and experience relative to the practitioners for which the commercial software packages have been developed.

The last strategy is to encourage and provide opportunities for self assessment of the quality of their work. In Engineering and Design II, they are required to make the mass comparison. Students know even before we sit down to assess their solid modelling whether they have done well or not. In the electronic reassembly exercise, the student's get immediate feedback on the quality of their work just based on the quality of the fitting that they see. In Material Science, students are required to compare their FEA results against their own simplified hand calculations. In Fluid Mechanics, students are required to compare results against literature or laboratory data. All of these self checks are expected of practitioners and are consistent with intelligent use of the software. This strategy is targeted at creating good habits among the students.

The greatest measure of whether we are being successful is examining if the CAD/CAE concepts have been retained beyond second year and if a true interest in CAE design has been fostered. We believe this can be initially measured by looking at the CAD/CAE oriented projects being developed in the senior year.

The results of the intelligent CAE use exercise are provided in Table 1. It is encouraging to see that the majority of the feedback from the evaluation of the capstone projects was towards the professional level. Overall we are quite pleased with the results. The fact that we did get some negative results for over simplification of the problem, model convergence, validation and boundary condition/material property assignment raises concerns. At this time it is difficult to assess the root cause of these deficiencies. The deficiencies are possibly a reflection of our practices in second year, a reflection of other supporting courses, a reflection of the quality of the particular teams and/or a reflection of the capstone design advising that was provided. Further assessment of previous and future capstone projects will be conducted to help in the assessment of the second year initiative. The next evolution in our use of CAD/CAE will be developed in light of these initial observations of the capstone design projects. The exercise has proven to be quite enlightening and it is anticipated that the technique will be extended to assess success in other areas of design competencies.

Summary

Over the past five years, since introducing CAD/CAE, we are now at a point where approximately 25% of our capstone projects have some sort of CAE component. Our venture into CAD/CAE education shows that it can be integrated relatively quickly into the curriculum and advanced senior projects can come forth. The School has also had alumni go on to work in various aspects of the CAE industry.

The results from our investigation into retention and maturing of CAE knowledge for students in there continuing studies was successful preliminary exercise. Further work will be conducted to help critique our program more precisely and accurately.

We have observed that students are excited by the prospect of creating either real or virtual prototypes. They feel that by using CAD/CAE in their designs they are incorporating cutting edge industry techniques and are acquiring marketable skills. This has helped to foster an enthusiastic and creative atmosphere among the students.

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Table 1 Indicators of Intelligent CAE Use

Was the use of CAE appropriately integrated into the design as a whole? (as opposed to unnecessary and disconnected from the design's objectives)			
Professionally	Partially	Incorrectly	No Integration
3	1	0	0
Was the design problem simplified?			
Professionally	Insufficiently	Overly	No simplification
2	0	2	0
Was there an effort to obtain a converged solution through refining the mesh?			
Professionally	Partially	Incorrectly	No effort
0	2	0	2
Does the model represent the boundary conditions and material properties of the actual setting?			
Professionally	Partially	Incorrectly	
3	0	1	0
Was there an effort to validate the results through comparison with existing data or other evaluation techniques? (possibly achieved through appropriate recommendations)			
Professionally	Partially	Incorrectly	No effort
2	0	0	2
Were the results interpreted correctly?			
Professionally	Partially	Incorrectly	No interpretation
2	2	0	0