AC 2007-831: PROJECT-BASED SOFTWARE APPLICATION ANALYSES IN UNDERGRADUATE HEAT TRANSFER

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Abstract:

As new engineering analysis software codes for mechanical engineers become available, it is incumbent upon academic programs to introduce students to these tools and for the students to develop at least rudimentary skills in the application of these codes. The issue that arises is how to effectively introduce these tools into a curriculum that is already crowded. As engineering programs struggle to find accommodations, many students reach their senior year before realizing an opportunity to apply these sophisticated analysis methods- frequently with little or no training. A recurring example is that of students' a priori construction of a system component followed by a perfunctory stress analysis using a commercial computer code. Often the analysis performed is irrelevant or incomplete. The notion of analysis being an essential element in the design process can be lost in the minds of many students. Therefore, the ME department faculty at SDSM&T together with campus partners are integrating into the traditional junior-level core curriculum project-based software applications and tools such as FLUENT and ABAQUS. This paper discusses a proposed option to the traditional offering of an undergraduate course in heat transfer. The method proposed brings project-based learning and analysis applications into the classroom in a novel way.

Introduction

ABET accredited engineering programs are required to include a high-level of engineering design within the program curriculum. ABET defines engineering design as[1]:

"Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."

Under Criterion 3, of ABET's *Program Outcomes and Assessment*[1] [(Outcome c)]:

"The engineering programs must demonstrate that their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."

To meet these requirements, students must demonstrate ability in all a-k outcomes under Criterion 3, the majority of which have as a foundation an implicit expectation of the students' ability to conduct valid engineering analyses and verification. Tools used to perform engineering analysis range from analytical (direct application of math and engineering science), to hardware (laboratory data acquisition), to software (commercial computer codes). In this paper, only the software tools are considered.

As new software developments become available, it is necessary to introduce students to these tools and for them to develop a basic capability in their application. This is an expectation of constituencies both external (governing boards, advisory boards, and employers) for maintaining currency in the discipline and internal (administrators and students) for maintaining graduate competitiveness in the work force. Faculty members themselves sometimes expect students to apply modern computer software tools such as FLUENT[2] and ABAQUS[3] in the course of their design project assignments.

At South Dakota School of Mines and Technology (SDSM&T), students, under the tutelage of faculty advisors, have successfully employed advanced engineering software in their design projects. For example, students have applied FLUENT to successfully assess lift and drag over airfoils being designed for the SAE Aero-Design[4]. Students have also applied ABAQUS to perform valid stress analysis of frame structures for the SAE Mini-Baha[5]. Far too often, however, we find that, during design reviews, many students, when questioned about some facet of their computer analysis, are unable to provide appropriate responses. Our internal assessment of this issue indicates a lack of proper student training early in the curriculum in the application of state-of-the-art commercial software. We found that most ME students at SDSM&T reach their senior year before being introduced to many of the analysis tools appropriate for complex design analyses. Faculty members, therefore, have proposed integrating software applications into the sophomore and junior-level curriculum. Since this proposal would adopt a sweeping change to the traditional method of offering a core engineering science curriculum, it was decided to beta-test the approach in one course- Heat Transfer. The paragraphs and sections below present the approach used in bringing project-based software applications into our undergraduate heat transfer class.

Computational Mechanics in Heat Transfer Class- Opportunities and Challenges

Computer equipped classrooms in the Computational Mechanics Laboratory (CML) at SDSM&T, allow the opportunity to conduct studies using computationally-intensive commercial computer codes such as FLUENT[2] on high-end workstations as part of the curriculum in the ME heat transfer course. However, at least two challenges arise: one, how to introduce these tools into a curriculum already crowded; and, two, how to come up with applications, not simply contrived applications, which will engage the students' in learning.

Introducing FLUENT in Undergraduate Heat Transfer

On the face of it, the first challenge can be addressed in two ways: one, practice the zero-sum exercise by priority elimination/addition of course material; or two, revamp the curriculum to accommodate a shift to project-based learning in the engineering science core while maintaining the analytical/theoretical foundation of the courses. We are pursuing the latter, but adopting the former on a preliminary basis for our heat transfer course.

Table 1 shows a comparison between the amounts of classroom time spent on subject matter in ME 313 (Heat Transfer) historically with that from the Fall 06 semester, the first semester that the project-based applications using advanced engineering software

(FLUENT) were introduced. The weeks indicated are calendar weeks consisting of three fifty minute class meetings on Monday, Wednesday, and Friday. As presented in Table 1, to accommodate project-based applications meant eliminating subject matter covered over the fifteen-week semester. In the Fall 2006, *natural convection* and *heat transfer with phase change* were not covered during the semester.

Table 1. A Comparison of the Modified and Original Heat Transfer Curriculum

Semester Weeks		**Topic**
Fall 2006	**Historical**	
4	4	Steady 1&2D Conduction/Numerics
1		Computer Lab Applications I
2	2	Transient Conduction/Numerics
3	3	Convection
1		Computer Lab Applications II
	1	Natural Convection
	1	Heat Transfer with Phase Change
1	1	Heat Exchangers
3	3	Radiation
15 (total)	15 (total)	

We are currently investigating significant modifications to the engineering science curriculum. For example, in the thermal science curriculum we are examining changes that would allow integrating the four-course sequence, including Thermodynamics I & II, Heat Transfer, and Fluid Mechanics into a five-course sequence, Thermal Science I-V, each 3 credit hours. Such a curriculum modification would allow adequate time to incorporate multiple computer labs and cover all topical subjects. The addition of three credit hours to the thermal science curriculum, however, will come at the expense of three credit hours elsewhere in the curriculum. One possibility being considered is replacing one senior elective with Thermal Science V.

<u>Developing Student-Engaging Projects in Heat Transfer</u>

Anecdotal data indicates that most students appreciated the introduction to FLUENT in Heat Transfer, but the opinions obtained varied somewhat. We believe that the student motivation to learn how to apply the software is there but that engaging the student will require projects that have intrinsic value outside as well as inside the classroom. Therefore, as for the second challenge listed above- that of developing project-based applications to engage students, we have enlisted the aid of the Center of Excellence for Advance Manufacturing and Production (CAMP) and the Advanced Material Processing (AMP) center, both centers are routinely engaged in collaborations with the ME program.

CAMP and AMP

Under the mentoring from faculty, students engaged in CAMP and AMP projects are successfully employing advanced analysis concepts in their designs. The objective is to spread this type of analysis success across the curriculum in the ME program. These centers are discussed briefly below.

Center for Advance Manufacturing and Production (CAMP)[6]

Many multidisciplinary teaming activities for student projects at the SDSM&T are coordinated and supported through the Center of Excellence for Advanced Manufacturing and Production (CAMP). CAMP supports the Formula SAE[7] (Figure 1), SAE Aero Design[4], SAE Mini Baja[5], and the ASME Human Powered Vehicle[8] , most of which are led by mechanical engineering students. The projects in CAMP have become important tools for student development in teaming and leadership. They are also important for deepening and broadening the technical discipline understanding. As discussed below, sophisticated analyses, subject-based, are being conducted on CAMP projects.

Figure 1. SDSM&T SAE Formula Mini-Indi- 2006

Mechanics of Materials – Solidworks/ABAQUS – For instance, frame development is important in the vehicle projects. Frames must be evaluated and ultimately chosen based on evaluation of weight, stiffness, stress, and fatigue characteristics. The weight can be determined with sufficient accuracy using a CAD tool (Solidworks)[9] and stiffness can be determined with sufficient accuracy using the FEM analysis tool ABAQUS[3].

Fluid mechanics – FLUENT[2] – Teams use FLUENT for flow and heat transfer analyses. For example, the SAE Aero Design team uses FLUENT to evaluate lift and drag on airfoils. Such information is available from handbooks, but the center of lift, a very important parameter in design and tuning, is not available with the accuracy required to be competitive in these team competitions. Therefore, the students need to apply the code to accurately determine these design parameters and can verify the results through comparison to less accurate published results.

Dynamics – COSMOSMotion[10] (based on ADAMS) – Chassis and suspension design are important for both the Formula SAE and Baja SAE projects. Teams build full 3-D designs of their systems in the CAD package Solidworks and import the CAD model into the commercial software package COSMOSMotion to investigate the dynamic behavior of shocks, springs, and suspension members.

Adavance Materials Processing (AMP)[11]

The Advanced Materials Processing Center (AMP) employs student/faculty teams to investigate material joining research/design issues. The latest in the state-of-the-art Friction Stir Welding (FSW) equipment is available in the AMP center. Currently, AMP projects involve over 30 graduate and undergraduate students from across campus. AMP provides students with:

1. Sponsorship and mentorship of capstone senior design projects,
2. Laboratory employment,
3. Undergraduate research opportunities.

Capstone Senior Design Projects – The AMP center routinely sponsors senior capstone senior design projects (fourteen over the last three years). These projects raise issues the students will encounter during their industrial careers – starting with the development of an agreed to "statement of work" between the student team and the AMP "customer", leading to a design that has undergone the rigors of design analysis. AMP personnel together with faculty mentors define the project goals, design constraints, budgets, schedule, and deliverables.

Laboratory Employment – Several of students working on senior design projects and/or undergraduate and graduate research projects are employed by the AMP center. These students and those who are not directly employed by the AMP center but working on AMP projects receive professional guidance in designing and conducting experiments.

Undergraduate Research – The AMP center offers undergraduates with an opportunity to become involved in leading edge research in joining processes and analyses. Students attend regular meetings of the research team and are expected to contribute to reaching the research objectives.

It is apparent that the scope and nature of the undergraduate AMP projects (Table 2) offer a variety of project-based learning and analysis opportunities, based upon real-world design challenges, which can be brought into the classroom. The ME program is planning to exploit this capability, experience, and expertise, to bring opportunities to do meaningful design analysis into the undergraduate engineering science curriculum.

Table2 – Summary of AMP Project-Based Learning and Analysis Experiences

Year	Department	Project Type	Project Topic
2006	ME	Capstone Senior Design	Development of Linear Ultrasonic Welding Systems
2006			Development of FSW Engine Cradle
2005			Developmen of Environmental Chamber for Titanium FSW
2005			Evaluation of Ballistic Impact of Aluminum FSW
2004			Development of Friction Stir Spot Welding System Prototype
2004			Evaluation of Friction Stir Spot Welding Rivet Repair
2004			Developmentof FSW Rapid Reconfigurable Tooling
2004			Tension Testing of Rock Climbing Equipment
2003			Development of Induction Preheating System
2003			Design and Development of LPD Chamber
2003			Design of Hybrid Beam Structures
2003	CSE	Capstone Senior Design	AMP Paperless Management Systems
2004	CEE	Capstone Senior Design	FSW Repair of Aircraft Wing Spars
2003			Compression Testing of FSW Structures
2006	CAMP	Mini Baja Competition	Tensile Tests of Welded Tube (1/4 sections) Frame
2006			Polaris clutch taper measurement
2006	CAMP	Formulae SAE Competition	Frame Reverse Engineering
2006			Front crumple zone compression test
2006			Reverse engineer polaris two cylinder engine
2006			Reverse engineer polaris single cylinder engine
2006			Reverse Engineer Seat contours
2006			Upright pin shear strength tests
2007			Frame Reverse Engineering
2006	ME	ME CAD/CAM	Dimensional Verification of CNC test part
2006	ME	ME Product Development	Class demonstration of strain gauges - Jason Ash
2006	ME	ME 322 Machine Design	ME322 Lab Tensile Demonstrations for Class
2006			K1C Fracture Toughness Demonstration for Class
2005	CEE	NSF RET Project	Design of Beryllium Containment Chamber for FSW
2005	CEE	NSF REU Project	Devlopment of Pin Tools and Processes for the FSW of Steel Alloys

Cohering Undergraduate Engineering Science and Design Analysis

Those projects that do require sophisticated code analyses, such as those discussed above with the CAMP and AMP centers, are under the strict guidance of a faculty member familiar with the software. The program objective, however, is to bring a level of training in application of these sophisticated analysis software tools to all upperclassmen in the ME program and to do it in a manner that engages the student and takes advantage of past department collaborations with the CAMP and the AMP centers. In addition to the training in software application, we want the students to develop the enthusiasm seen in students working on projects in CAMP and AMP. We, therefore, want to engage staff from these centers in developing and offering these classroom projects. What we have proposed is the following:

1. Set aside 2-3 academic weeks during the semester for intense computer laboratory training in the use of the relevant software. For example in thermal science classes the software would be FLUENT. For solid mechanics classes the software would include ABAQUS.
2. Early in the semester, meet with staff from AMP and CAMP to lay out appropriate projects for classroom applications. These projects need to:
    a. be limited in scope,
    b. align and sequence with subject material being taught in the class, and
    c. support current AMP and CAMP projects.
3. As with CAMP and AMP, these projects should produce an environment similar to that the students will encounter during high-level capstone design activities and should include specific tasks such as "statement of work" and "deliverables".
4. Staff from CAMP and/or AMP should co-lead the class during this teaching/learning process.

As an example, we have developed a design analysis project for the Spring 2007 offering of Heat Transfer. The following section briefly presents the project description.

Project-Based Software Application in Heat Transfer Class

The project to be introduced in the Spring 2007 semester of Heat Transfer is a collaboration with the AMP center involving friction stir welding. The project is discussed below.

Friction stir welding (FSW) is a process that is gaining interest in all industries that use conventional welding to join two metals to each other (Figure 2). Basically, the process involves clamping the two pieces to be welded together to form the joint and forcing a rotating pin between the joints and moving it along the joint. Friction between the surfaces brings the material to a plasticized state (no melting) with the result being a high quality bond.

Project Statement – With the gaining interest in FSW comes a need for a better understanding of the phenomena involved. This need includes quantifying the work transferred to the metal work piece by the pin. This is a challenging task since the process involves heat lost through both the pin of the friction stir welder and through convection from the surfaces to the outside air.

Project Approach – AMP personnel will provide the FSW operating parameters (material, pin design, pin speed, etc.) The power from the pin transferred to the welding piece will be quantified by equating the power to the time rate of change of the internal energy of the work piece. By carefully designing the work piece so as to minimize any temperature gradients in the material, the resulting temperature response can be used to directly calculate the energy entering the work piece. With no temperature gradients to account for, a lumped capacitance heat transfer model can be employed - an area of heat transfer studied early in the semester. Both numerical and experimental results will be obtained.

Project Schedule – The project will be conducted in three applications:

1. Develop and verify (exact solutions) finite difference models with various boundary conditions (in class week 3-5 of the semester)
   a. Steady-state,
   b. Transient,
2. Develop a FLUENT model (lab class week 6 of semester)
   a. Compare results with the finite difference models,
3. Verify numerical results (lab week 10 of the semester)
   a. Design AMP center FSW experiment,
   b. Conduct experiment,
   c. Document data,
4. Report (hand in last week of semester).

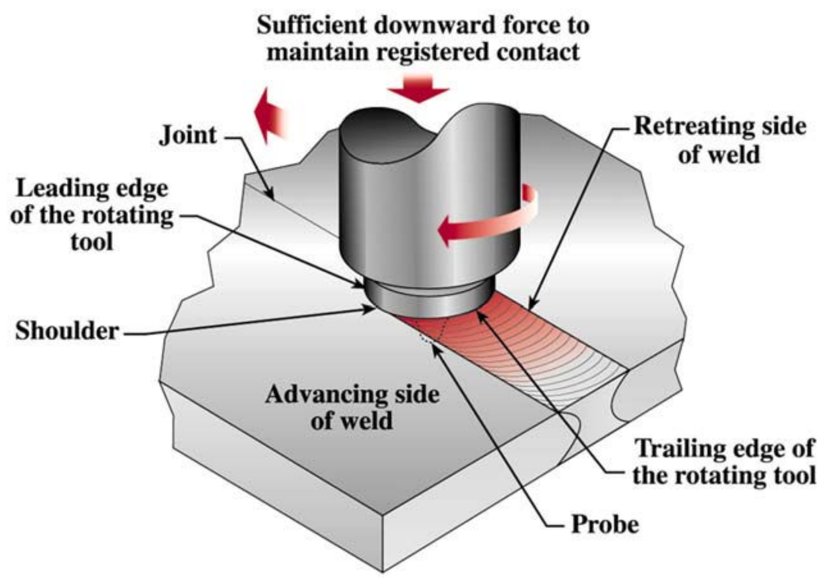

Figure 2. Depiction of FSW

The project encompasses several elements of heat transfer covered early in the semester including:

1. Steady and transient conduction,
2. Boundary conditions,
3. Convection,
4. Heat generation.

<u>AMP Deliverables</u> – A final report(s) will be delivered to the director of AMP. Included in the report will be a documentation of the energy transferred from the FSW pin to the work piece and the accompanying machine thermal efficiency (based upon the measured torque and pin speed). Additionally, results from the FLUENT model will be verified through comparisons with experimental data. It is anticipated that, to minimize machine time and costs of conducting experiments, future research will apply FLUENT models to generate data required to perform an extensive dimensional analysis for various process

parameters, which will be of significant value to AMP in quantifying the effects of these parameters on weld quality and eventual design implementations.

We believe the nature of this project will attract students and entice their active participation. We expect that the students will appreciate the advantages of applying sophisticated commercial software to engineering design and will take this appreciation to their senior year and their capstone experience. We also anticipate students presenting results from this project at regional and national conferences on FSW.

Conclusions and Comments

The ME department at SDSM&T has presented a plan for synergistically engaging students, faculty, and staff of technical centers in project-based learning activities in a real world environment that benefit all, but primarily the student classroom experience. We have encountered problems, however, including introducing additional course content into a burgeoning curriculum. From a short-term perspective, we have employed a zero sum approach to accommodate this additional content but we understand that the long-term solution is more complex and will require periodic review of the overall program curriculum content and sequence.

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