Session 1566

A Project-Centered Approach to Teaching of Thermal-Fluid Systems Analysis and Design

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Abstract

In the fall of 1998, the Thermal-Fluid Systems faculty in the Department of Mechanical Engineering at the University of Texas at Austin introduced a new junior-level course, ME343 Thermal-Fluid Systems, which replaced a long-standing second course in thermodynamics. This course caps a three course sequence in fundamentals of thermodynamics, fluid mechanics, and heat transfer. It is intended to deepen students' understanding of material covered in the three fundamentals courses, to extend their knowledge base in selected areas, and to tie the fundamental areas together in the context of engineering systems. We also wish to enhance students' ability to apply computer tools, to research engineering literature, to self-teach, and to communicate.

It was decided that the most effective way to accomplish these goals was to center the course around an in-depth study of one or two specific systems each semester. Students, working in teams of 3 or 4, are required to analyze the underlying engineering issues that govern the design and performance of the system, develop computer models, perform parametric studies, and prepare a comprehensive report summarizing their analysis and conclusions. "Just-in-time" theory is presented in class to support these activities as they evolve. Examples of systems used to date include commercial aircraft and their turbofan engines, Diesel and gas turbine cogeneration systems, domestic refrigerators, building HVAC systems and heating systems for semiconductor processing equipment.

This paper describes our approach to selecting, organizing and implementing projects, presents examples of projects used in the course, and describes methods for assessing the effectiveness of the project-centered approach in courses of this type.

Introduction

Every mechanical engineering program includes a set of core courses in the thermal-fluid sciences (TFS): thermodynamics, fluid mechanics, and heat transfer. These fundamental topics are at the heart of all energy conversion systems, and courses focusing on each area have been an important part of the mechanical engineering curriculum since the inception of the field.

The contents of these courses are almost universally accepted throughout the world, and excellent textbooks are available, all of which follow nearly identical outlines. The teaching approach is traditional: lectures and problem sets, in some cases supplemented with simple structured lab experiences.

Teaching the application of TFS to real systems, however, is much more difficult, because invariably real systems entail the interaction of all of the component disciplines, and in most cases the application requires a more advanced understanding of basic theory than is covered in the respective introductory courses. For example, the thermal-fluid design of a jet-engine requires modeling of combustion and compressible flow processes which are often omitted in first courses in thermo and fluid mechanics.

A number of good textbooks have been marketed during the past decade which attempt to integrate the elements of TFS into the overall context of system design. The task of covering advanced topics while at the same time illustrating how they interact in various types of systems is daunting, however, and impossible to achieve in a single work of reasonable size; thus each of the available works tends to focus on a particular area central to a particular class of applications, while omitting others entirely.

Prior to 1998, the TFS curriculum at the University of Texas at Austin consisted of five courses, one each in introductory fluid mechanics and heat transfer, two in thermodynamics, and a lab taken after completion of all of the theory courses. All of the theory courses were taught via the conventional lecture/problem approach. Starting in the fall of '98, a new course, ME343, Thermal-Fluid Systems, was created to replace the second thermo course. We decided to utilize a project-centered approach in teaching ME343, one in which we would focus on the analysis and design of a particular real-world system and introduce new fundamental topics on a "need to know" basis. The approach places heavy emphasis on student-initiated learning, teamwork, computer modeling, and communication. We now have accumulated several years' experience with ME343; in this paper we will outline what we have learned about the project-centered approach and its implementation, along with examples of specific projects and assess-ment methods.

Desired curricular outcomes for ME343

The ME Department at UT Austin is in the midst of a major curriculum reform effort called by the acronym PROCEED (for Project-Centered Education), spurred in part by experience with courses such as ME343. As with engineering programs nationwide, we are now defining individual course objectives in terms of more generic programatic outcomes. The department has defined ten such desired outcomes, similar but not identical to the ABET "a-k" list. The traditionally taught second-thermo course which ME343 replaced was almost entirely oriented toward deepening the fundamental theory element of the TFS curriculum. When we created ME343, we decided to broaden the scope of the course to place significant emphasis on several more general outcomes, including solving of open-ended problems, applying computer tools to design, working in teams, and professional communication. The project-centered approach lends itself naturally to integrating these various elements of engineering practice with the teaching of fundamentals. However, it also necessitated tradeoffs between breadth (in terms of the total number of theory topics covered) and depth (the time spent intensively applying a fewer number of topics). These tradeoffs are discussed below.

Rationale for using the project-centered approach

The value of projects as a tool to enhance learning is not a new idea [1]. The project-centered learning approach (or more commonly, "project-based-learning", PBL) has been extensively applied and found effective in K-12 science, legal and medical education as well as engineering. A substantial body of literature supports the thesis that PBL substantially improves long-term retention and "deep understanding" (the ability to extrapolate scientific knowledge to subsequent learning experiences and new situations) (Barron et al [2], Blumenfeld et al [3], Williams [4], and Bransford et al [5]). Our application of this approach to the study of thermal-fluid systems is motivated by several factors derived both from the the research literature and our own engineering and teaching experience.

"Just-in-time" theory: The TFS faculty felt that certain fundamental topics which were either previously taught in the second-thermo course, or which are covered in a cursory way in our introductory fluid mechanics and heat transfer courses, are essential for graduating mechanical engineers; these include, for example, combustion, psychrometrics, power and refrigeration cycles, heat exchangers, and some elements of compressible flow. In ME343, we select projects which require the application of these topics and teach the requisite theory on a "just-in-time" basis, i.e.,when the students encounter the particular element of the system that requires it. If an important topic is not integral to the particular project, it is covered by the instructor as the schedule permits. In some cases, we undertake two projects addressing different types of systems in the course of a semester, enlarging the range of possible topics that are pertinent. We find that presenting theory in the direct context of a specific problem waiting to be solved generates a sense of urgency which places students in the "active listening" mode much more effectively than when theory is presented out of context.

Understanding the concept of systems analysis: In most traditionally-taught courses, problems are carefully limited in scope to focus on a particular phenomenon or method of interest, and data is specified such that there is only one "right answer". Students have become acculturated to this highly structured environment, which is not a good representation of real engineering. A primary goal in this course is the integrated presentation of all the thermal-fluid disciplines, as well as others such as materials, mechanics and economics, in a project which requires a "systems" treatment. This invariably requires computer modeling of the system to permit parametric analysis and tradeoff studies, both technical and economic. This task is alien to most students at the junior level and many struggle with it, while others relish the challenge. After becoming acquainted with the systems approach, however, most develop a higher comfort level and appreciation for the deeper understanding which comes with examing system behavior from multiple perspectives.

Motivational value of real-world applications and industry interaction:
Project-centered courses such as ME 343 provide the students with a ‘real world’ experience that they do not get in traditional lecture/problem courses. While projects may vary considerably in their specifics, as will be illustrated later, they generally fall into one of the three categories: (a) projects originating from industry as a result of an association between a faculty member and an industrial contact, (b) projects involving a power/ refrigeration system in use at the university, or

(c) an energy system application developed by a faculty member based on a real system described in the engineering literature. In all cases, we base our projects on real hardware for which actual performance data can be obtained, and against which the students can test their solutions. In some cases, tours are arranged of facilities on which a project is based, or engineers who have been involved in the design and operation of the system are invited to consult with students. In some instances, direct testing of and/or obtaining measured performance data for the system under study provides a valuable learning experience vis a vis testing and data analysis.

Development of professional skills and extended-project experience: The project-centered approach used in ME343 permits students to develop professionally in a number of ways. The development of a "systems mentality" and the experience of working on a real engineering system with real hardware have already been mentioned. Projects are carried out in teams and extend over a period of weeks. Thus students gain experience in both the benefits and liabilities of teamwork: brainstorming, work planning and scheduling to accomodate the differing commitments of the various members of the team,, following through on commitments, and simply working with and depending on others in a professional environment. These experiences are new to most students and are sometimes painful. Failure to plan and work effectively as a team can greatly increase the amount of work and the anxiety associated with it. In the end, however, once the crisis has passed, students are generally appreciative of the opportunity to work in a professional environment and acknowledge the learning value of the team experience.

Examples of projects used in ME343

As pointed out above, projects are chosen for use in ME343 on the basis of their compatibility with topical requirements of the course, their connection with real hardware for which performance data is obtainable, and the accessibility of resources such as expert engineers from industry. These are illustrated by the following examples of projects which we have used in the course since 1998.

Aircraft and propulsion system performance: In this project, which we have used several times, we select a jet aircraft (generally a commercial transport such as the Gulfstream V long-range business jet) and its associated engine (usually a turbofan). The internet and Janes' All-the-World's Aircraft generally provide a rich base of technical data on both the airframe and the engine, and manufacturers have always been generous in providing additional data and resource materials (e.g., cutaway drawings and equipment photos) within the limits permitted by proprietary considerations. Predicting certain performance parameters of the overall aircraft, such as takeoff length and cruising range, provides a good basis for an in-depth review of aerodynamics and highlights how critical the engine performance parameters (e.g., specific thrust and specific fuel consumption) are to achieving aircraft performance objectives. This sets the stage for a detailed thermodynamic analyis of the turbofan. The students develop a computer model, starting with an idealized cycle and then introducing a series of refinements requiring a knowledge of psychrometrics, gas mixtures, combustion, and compressible flow. Finally, students carry out parametric studies of engine performance as a function of design and operating parameters. Since the projects described require little heat transfer consideration, we have also experimented with having students do a short project exploring the heating and cooling loads on aircraft and the design of thermal comfort system to meet passenger needs.

Initially we focused only on propulsion system performance (thrust available) without having the students develop any background in aircraft performance (thrust required). We have found an appropriate level of effort on both subjects works better than a more extended analysis of the powerplant alone, as it places the engine in context of its application.

The aircraft/engine project requires that students make extensive use of reference material beyond what they can find in their TFS textbooks.This is somewhat of a revelation to many, who are sometimes amazed to discover where the engineering library is and what valuable resources it contains.

Gas turbine cogeneration and combined cycle system: The University of Texas at Austin generates its own electrical power. The heart of the primary generating unit is a Siemans-Westinghouse 251B combustion turbine coupled with a Henry Vogt heat recovery steam generator. We have used this unit as the basis of the semester project in ME343 four times. One of the primary reasons for this choice was that (at least prior to 9-11) we had good access to this facility and could take the students through the plant to give them a feel for the size and layout of the system. The students responded enthusiastically to the tour and the project. Modeling of the gas turbine and heat exchange processes began with textbook examples and grew as the students sought out more specific information from engineering literature and manufacturer data. The power plant director also provided access to some actual performance data. Interestingly, we found that the student-(and to be honest, faculty-)generated models for simulating system performance frequently departed significantly from actual operating data. But we found this really to be somewhat of an advantage, as time spent trying to determine why the models did not work was very enlightening. The inadequacy of the models led to very useful discussions of how the system really worked and why many assumptions, both explicit and implicit, led to error. Modeling the heat recovery steam generator proved to be much more difficult for the students than modeling the gas turbine. Understanding differences between design and performance modeling also proved to be challenging. However our experience has been that more learning takes place when projects don't go smoothly than when they do. Some care must be taken to be sure the students don't become too discouraged, but they come out of the class with a greater appreciation of what engineering practice is really all about.

Dual fuel diesel on-site power/cogeneration system: A project that has been used on more than one occasion is the analysis of a dual-fuel diesel power generation system. We are fortunate to have a major 3M Corporation facility in Austin which provides all its own power, cooling and service heat and hot water from a central plant. The heart of the system is a Cooper-Bessemer Gas/Diesel (LSVB-20) engine-generator set operating in cogeneration mode. This is a turbocharged 20 cylinder, 8000 hp unit that can operate on either natural gas, diesel or mixed fuels. 3M personnel have been very cooperative in providing our classes with guided tours of the facility and technical support. Cooper-Bessemer provided us with extensive performance data for this system operating in both fuel modes, and an excellent paper from an ASME Journal describes research and development on this specific engine aimed at reducing emissions. Depending on the semester, the project has considered only the engine itself, the engine and cogeneration equipment, the engine and a hypothetical oil cooler using ambient air, and the turbocharger design and its effect on engine performance. A computer model has been developed for the performance of the engine operating under varying load using either fuel, and students are able to compare the calculated results with Cooper-Bessemer's actual performance data. This provides an excellent opportunity for the student see the equipment first-hand, to analyze reliability and estimate uncertainty of measured data, and to rationalize why model results deviate from actual performance data.

Reverse engineering of a domestic refrigerator: The refrigerator project is to date the only one we have used in which students actually set up and run real hardware. Two identical dorm-size refrigerators were purchased, one of which was maintained in running condition and instrumented so that students could acquire performance data; the other was "sacrificed" to allow students to measure insulation thickness, size and configuration of the evaporator and condensor heat transfer surfaces, and compressor parameters such as bore and stroke. These data were used to model the system, predict heat loads, and estimate power requirements, which were compared with measured data and published specifications. As is often the case, the project produced some surprises that led to fascinating discussions and detective work. For example, it was discovered from apparently inconsistent temperature measurements that the capillary tube expansion device was actually integrated into a tube-in-tube heat exchanger for regeneratively cooling the refrigerant entering the evaporator. Similarly, an apparent violation of the Second Law (compressor discharge temperature lower than isentropic) produced the discovery that the tubing connecting the compressor discharge to the hermetic casing was intentionally elongated and coiled inside the casing to serve as another regenerative device. The students enjoyed this project immensely; even though they initially found it frustrating that their simplified model of how the refrigerator was configured was off-the-mark. The thrill of discovering what was really going on and eventually making sense of their measurements was ultimately very satisfying, in a way that solving textbook problems could never match.

HVAC system and component sizing for an office building: One of the authors has periodically offered a specific elective course on HVAC System design, but this course, which goes into considerable depth, is usually taken by a limited number of students. We find that this topic is well suited for a semester project in the more general ME343 course, as it provides a good application and review of all three of our fundamentals courses. In this setting, heating and cooling load calculations, thermal distribution, and refrigeration systems design are examined, but issues such as air quality, thermal comfort and control that are included in the elective course are omitted to make time to address other more general TFS items. Students are given a defined space, such as a single floor of a commercial office building, and asked to determine the hourly heating and cooling loads on the space for three days representing different seasons. They then must lay out the thermal distribution system (duct work) and design and model a heating and refrigeration system to meet the needs of a building consisting of ten such floors. One variation on the office building case study that we have used is the design of the HVAC system for a small printing plant. In this application, humidity control is critical, as is ventilation to maintain concentrations of solvent vapors within acceptable air-quality and explosion limits. As always, these projects are open-ended, and while students, can start from their existing texts, they are required to search for additional information in engineering literature (handbooks, technical papers, on the internet, etc.). The challenges students encounter with this project are obtaining and organizing information and data, making appropriate assumptions, building and evaluating parametric models, and judging the adequacy of the results, in other words, an accurate model of engineering in the real world.

Heat transfer system to maintain temperature control in semiconductor wafer processing chambers: This project entails the reverse-engineering and design of a heat transfer system to maintain chemical-vapor deposition (CVD) chambers at a given temperature for semiconductor production. The system includes a heat exchanger, electric heater, pump, particulate filter and deionizing column, and several of temperature, pressure and flow controllers. While for the most part it is a rather conventional thermal-fluid system, there is a unique aspect with respect to estimating the heating load that the system must deliver to the process. The CVD process maintains a radio-frequency plasma environment in a vacuum chamber in which an electrically heated silicon wafer sits on the bottom. The calculation of the combined radiative (internal) and convective/radiative (external) heat transfer to and from the chamber walls is challenging and requires that students revisit and carefully consider these topics from their basic heat transfer course. The project has also provided a good opportunity to expose students to the mechanically-engineered processes and equipment that are critical to an industry that is often viewed as the domain of electrical engineers.

Implementation issues

In implementing the project-centered ME343 course, we have had to confront a number of issues that depart from our prior experience with traditional lecture/problem teaching. One of the biggest is striking a proper balance between emphasis on content coverage and student centered problem solving activities. In our case, we have somewhat of an advantage in that the students have significant prior exposure to content in the three prerequisite courses. Thus, we have chosen to emphasize system analysis and design processes and introduce new content on a just-in-time basis to suit the requirements of the project. We also gage the extent of the coverage of specific topics by the extent of the expressed need / interest of the students. This makes scheduling more difficult, but it builds an increased sense of course responsibility among the students. This procedure has had a marked impact on increasing the level of participation of many (but unfortunately not all) of the students in the course. It has also served to keep the course instructors on their toes.

One means of providing course structure has been to assign a combination of concept questions and relatively short analysis problems as individual student homework (in contrast with team work). Concept questions provide clues to the students as to what information they will need to find and digest to carry out the project. Analysis problems, of course, have a similar purpose, but with emphasis on the computational and modeling skills that will be required. Ultimately, the actual project work is carried out by the team. However we encourage team members to work together to the extent of sharing information sources and discussing insights to complete their individual responses to the concept questions and analysis problems. There are two specific reasons for adopting this approach: first, to encourage the students to learn from each other, and second, to insure that each member of the team is prepared to contribute to the overall project.

Perhaps the most difficult implementation issue is determining just how open-ended the project should be. We have definitely come to the conclusion that our projects must take the students well beyond the experience offered by the short design and computer modeling problems found in the more recent textbooks. In order to simulate the real-world engineering experience, student teams must learn to define and clarify the stated project in engineering terms, to identify the information they will need and the resources available to provide that information, and come to grips with the reality of making judgments and drawing conclusions even when they don't have all the information they would like to have. Finally they learn that they must rely on themselves to solve the problem, as there may not be anyone (such as the instructor) who knows exactly what the solution approach should be or what the "right" answer is. On the other hand, the assigned project must not take the students to a level of frustration that leads them to simply quit trying. Finding the right balance is an interesting problem, particularly given the diversity of backgrounds, commitments, and capabilities that characterizes today's student population.

In working with ME343, we have found a difference between assigning projects that might be classified as 'reverse engineering' as opposed to 'original system design'. Students are clearly more comfortable with a reverse engineering project, at least up to the point of having to check their analysis against actual system performance data. With original design and analysis projects, they often have a harder time getting started but tend to be more comfortable (whether justified or not) with their results in the end. Each type of project has its advantages and disadvantages. If good performance data is available and the subject system can be modeled reasonably well, reverse engineering might be a better choice, because (1) it is easier for students to "benchmark" their results (i.e., there is a "right" answer of sorts), and (2) there is more opportunity for hands-on experience with real hardware. Original design and analysis projects can be more easily tailored to the modeling capabilities available, but lack the reality of a project based on an existing physical system.

A final issue is the number of projects assigned in a semester. We have experimented with one, two and three projects. Our consensus is that three is too many. With only one project, students tend to procrastinate; a whole semester seems like a lot of time for a single project. We have tried to overcome this by assigning a series of concept questions, analysis problems and intermediate memo-type reports that, taken together, lead naturally into a final comprehensive report. This approach works reasonably well but some students seem to lose interest before they are through. As a compromise, two projects work reasonably well, particularly if one is less extensive than the other. In this case, the projects must be carefully scheduled and balanced in scope to insure that one is not too rushed while the other drags on too long. Irrespective of whether one or two projects are employed, the importance of careful up-front planning cannot be overstated..

Course assessment: methodologies and results

During the first three years of ME343, we mainly employed standard course/instructor evaluations at the end of the semester to obtain feedback on how this approach was perceived by students. Course evaluations were initially lukewarm, but after several semesters of refining our approach, they have become very strong; anecdotal comments typically indicating that students consider the course near the top of the curriculum in terms of work-load, but also near the top in terms of learning gains. Perhaps most significantly, exit interviews with graduating seniors have frequently cited ME343 as one of the most valuable courses in the curriculum in terms of preparing graduates to enter "the outside world."

Over the past year, we have undertaken a much more comprehensive assessment process for ME 343 students using both qualitative and quantitative strategies. Qualitative data has included student and faculty interviews and classroom observations. While such methods provide rich data, they are time consuming and not practical for providing feedback on many courses on a continuing basis. Quantitative methods are more useful for repetitively covering a larger population. We have experimented with three different quantitative surveys. The first was a series of questionnaires about student attitudes and characteristics that we now refer to as the Undergraduate Survey. In summer of 2002, we piloted two other instruments: one an existing instrument, the Student Assessment of Learning Gains (SALG), and the other a modification of an instrument used at VMI that we call the QQI (for quantity, quality and improvement).

Undergraduate Survey: Traditional lecture-based engineering courses tend toward the so-called transmission model which is largely teacher-centered. Project-based courses are more student-centered, more open-ended, and involve more group activities. Many students are initially uncomfortable with project courses because they perceive them as requiring more work and effort on their part and are insecure as to what they are supposed to do "to make an A". We are experimenting with a series of surveys to see if students' attitudes about working on projects change from the beginning to the end of the course. Administering this survey at the beginning of the semester provides an attitudinal profile of the class that can help orient the instructor on where to place early emphasis. For instance, if the class is very negative about working in groups, the instructor may need to spend more time on team development at the beginning.

Online survey – SALG: As part of our pilot in the summer of 2002, we asked students in two upper division project-centered courses to complete the SALG outside of the course and to return a "survey-of-the-survey" with their input about this survey. The SALG instrument was developed at the University of Colorado at Boulder for use in assessing student learning gains in science, and it is available online [6]. Unfortunately, we had a very low return on both the SALG survey and on the survey-of-the-survey, so the results were inclusive. This particular effort was not well-received by the students who apparently perceived it as a research exercise with no benefit to them. If we decide to try it again, we will need to find incentives to improve our return.

QQI (Quantity, Quality, and Improvement) Instrument: In researching suitable processes for assessing the success of project-centered courses such as ME343, we found a survey developed by Addington and Johnson at VMI to be particularly interesting [7]. This survey looked at the quantity and quality of learning opportunities as well as student improvement in knowledge and skills relevant to departmental outcomes. The constructs measured here – quantity, quality and improvement – addressed efficiency and effectiveness in the classroom, two variables we are seeking to balance. By optimizing the quantity and quality of learning opportunities we can increase the efficiency of the classroom. Too many learning opportunities of low quality could be equated to busy work. By measuring student achievement, we are ensuring that our classroom remains effective. While we recognize that the accuracy of self-reported data of student learning gains is challengeable, we chose to use this method of data gathering since research has indicated that self-reported data can serve as a proxy for actual student learning gains for purposes such as formative assessment (Anaya [8], Sarin & Headley [9], and Somerton [10]).

We took the philosophy of the VMI survey and adapted it to our needs. In an effort to increase the validity and reliability, we expanded the definitions of the constructs of quantity, quality and improvement and defined detailed scale descriptions more directed our needs. This instrument was piloted in the summer of 2002, then modified and administered in fall 2002 in three sections of ME343 taught by three different instructors.

Our early analysis of data across all three sections surveyed in Fall 2002 has already yielded one important result in supporting our use of projects in the classroom. The results on the Undergraduate Survey, in response to the item

I like a classroom environment that :

1	**2**	**3**	**4**	**5**
let's me be creative and do things my way.				has lots of structure where I know what is expected of me.

indicated a statistically significant difference ($p<.05$) between the beginning and end of the semester. The mean for the first measurement early in the semester was 3.45 and the mean at the end of the semester was 3.1, a shift towards a student preference towards a more creative, less structured environment. Data analysis for the QQI surveys has not yet been completed..

Future Plans: Our current plans are to begin administering the QQI to all project-centered courses in the ME Department during the 2003-04 academic year. To expedite this, we plan to put the survey online where all information will go into a maintained database. In spite of disappointing experience with an online survey during the summer 2002 pilot test, we believe this method of collecting data will ultimately be the most practical, particularly if student participation can be increased.

Conclusions

Our adoption in 1998 of project-centered teaching for thermal-fluid systems analysis and design was a first experiment in what is now a department-wide movement to extend this approach to courses across the curriculum. Our experience indicates that while this approach is more time-consuming for both instructors and students, it offers important benefits in tying together a diverse package of fundamental tools and applying them to real engineering systems. Equally important, it forces students to develop their skills in computation and communication, as well as introducing them to the role of teamwork, planning, and interpersonal relations as an integral part of professional engineering practice.

Acknowledgements

The authors wish to express their appreciation to Ford Motor Company, Rolls-Royce Germany, Pratt and Whitney Division of United Technologies, Siemans-Westinghouse, 3M Corporation, Cooper Bessemer, and Applied Materials Corporation for their participation and contributions to the development of ME343, and particularly for sharing their expertise with our students.

References

1. Kilpartrick, W.H. (1918): "The Project Method", Teachers College Record, 19(4).

2. Barron, B.J.S., D.L. Schwartz, N.J. Vye, A.Moore, A.Petrosino, L.Zech, and J.D. Bransford (1998): "Doing with Understanding: Lessons from Research on Problem- and Project-Based Learning", J.Learning Sciences, 7 (3&4).

3. Blumenfeld, P.C., E.Soloway, R.Marx, J.S.Krajcik, M.Guzdial, and A. Palincsar (1991):"Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning", Educational Psychologist, 26 (3&4).

4. Williams, S.M. (1992): "Putting Case-Based Instruction into Context: Examples from Legal and Medical Education", J. Learning Sciences, 2 (4).

5. Bransford et al (ed.) (2000): **How People Learn: Brain, Mind, Experience, and School**, National Academy Press, Washington

6. Heady (2001): http://www.wcer.wisc.edu/salgains/instructor

7. Addington, J.S. and R.A. Johnson (1999): "Incorporting the Design and Use of Surveys With Other Assessment Methods Under Criteria 2000 ABET Guidelines", Proceedings of the 1999 ASEE Conference and Exhibition, Session 1332.

8. Anaya, G. (1999): College Impact on Student Learning: Comparing the Use of Self-Reported Gains, Standardized Test Scores, and College Grades, Research in Higher Education, 40 (5).

9. Sarin, S. and D. Headley (2002): "Validity of Student Self-Assessments", Proceedings of the 2002 ASEE Conference and Exhibition, Montreal, Session 3530.

10. Somerton, C.W. (2002): "Correlating Students' Evaluation of Their Own Learning with Classroom Performance", Proceedings of the 2002 ASEE Conference and Exhibition, Montreal, Session 3530.

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