

## **PROCEED: A Department-Wide Curriculum Reform Initiative in Project-Centered Education**

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### **Abstract**

The Department of Mechanical Engineering at the University of Texas at Austin has undertaken a major curriculum reform effort entitled PROCEED, an acronym for Project-Centered Education. The strategic objectives of PROCEED are: (1) to strengthen our students' understanding of fundamental engineering theory by continuously tying it to tangible objects and systems; (2) to strengthen our Department's connections with its industrial stakeholders by actively involving them in the development and delivery of curriculum content; (3) to provide our students with a broad range of team-based experiences which will better prepare them for growth and leadership in the corporate and professional world.

PROCEED was formally initiated in the fall of 2000. Overall curriculum goals were outlined and 13 pilot projects were initiated by the ME faculty. These projects cover the entire range of the curriculum, from the freshman introduction-to-ME course through the senior capstone design course. They include a number of reforms, including, among others, development of new labs which are closely integrated with core theory courses, using reverse-engineering of commercial products and systems to motivate analysis and computer modeling, development of an on-line student portfolio system to showcase project-centered work, and live-videoconferencing with corporate engineers to counsel with students on company-sponsored projects.

This paper outlines the background, motivation, and strategy behind PROCEED, how it is being implemented, examples of PROCEED pilot projects, and implementation issues and challenges.

### **Introduction**

The Department of Mechanical Engineering at the University of Texas at Austin is one of the largest in the US, with a total enrollment of over 1000 undergraduates and 200 graduate students. In 2000-01, the Department awarded 170 BS, 78 MS and 24 PhD degrees; US News and World Report ratings for that year ranked ME at UT 10th nationally at the undergraduate level and 11th at the graduate level.

As is the case with departments nationwide, UTME faculty have been evaluating the strategic directions in which we need to move to stay in the top tier in the decades to come. One of our top priorities, along with excellence in research and graduate education, is to produce new graduates with exceptional preparation for further professional study and engineering practice. One result of this priority is a new undergraduate curriculum reform initiative called PROCEED, an acronym

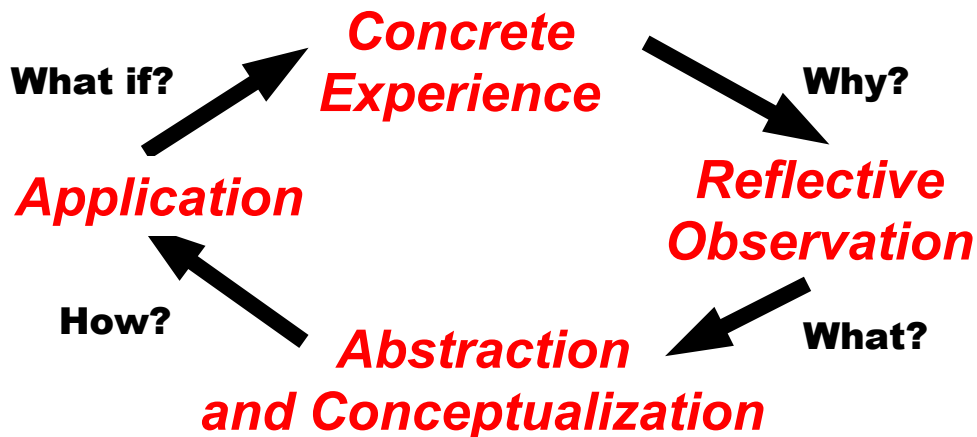
for "Project-Centered Education."

### **Rationale for PROCEED**

To put our rationale for PROCEED in perspective, it is helpful to briefly examine the history of engineering curriculum reform in the US over the past half-century. The launching of Sputnik by the Russians in 1958 and the ensuing space race of the '60s produced a huge demand for new technology, and with it a huge demand for more mathematically and scientifically-based engineering curricula. Engineering education traditionally had been heavily laboratory-oriented, but many lab courses went by the wayside to make room for more science and math. It is also worth noting that, up to this time, most young people came to engineering studies with a considerable amount of hands-on experience acquired by building and fixing engineered systems (cars, radios, appliances) and therefore a substantial body of conceptual understanding of how things work. This conceptual foundation provided a good framework on which to build a theoretical base of engineering science.

The emergence in the '70s of mainframe computers as engineering tools produced a demand for programming skills, and the introduction of programming and computing courses further forced lab studies out of the curriculum. The '80s brought the advent of personal computers and the rapid development of user-friendly application software. As increasingly powerful hardware and software tools became available, industry began demanding engineering graduates skilled in the use of these application tools, and showed less interest in students' ability to build their own tools from the ground up. The microprocessor also radically changed the way and extent to which pre-college students experience technology. Integrated electronics and the conversion of mechanical control to computer control effectively made function and form in everyday machines invisible; the conceptual database that engineering students formerly brought to the table declined substantially as "virtual" experience replaced hands-on experience and time spent "tinkering" was devoted instead to playing video games. The explosive growth of the Internet in the '90s brought instant access to detailed (but not necessarily accurate) information on any topic with little or no contemplation or reflection to provide broader perspective on its meaning. Taken as a whole, the trends described above have resulted in a phenomenon referred to by Frand <sup>1</sup> as "the information-age mindset", characterized by broad substitution of "virtual reality" for "reality", unquestioning acceptance of computer-based information, and a preference for "doing" as opposed to "knowing".

The traditional lecture/problem teaching approach that evolved in the latter half of the 20th Century has thus thrust today's engineering students into a highly theory-based learning environment with little intuitive understanding of the physical phenomena underlying the differential equations they are learning to solve. This represents an inversion of the Kolb Learning Cycle <sup>2</sup> shown in Figure 1.



**Figure 1: Kolb Learning Cycle**

The Kolb Learning Cycle describes a natural process in which individuals first acquire a "mental database" of experiences, more or less at random, by exposure to the real world. With repetition and time for reflection, connections between these experiences emerge and coalesce into concepts that lend themselves to formulation of abstract principles. These principles can then be applied to situations beyond those already present in the experiential database. Since, in the normal Kolb cycle, the abstract principles themselves are built on a base of actual experience, the individual has a natural basis for understanding when they can and cannot be reliably applied to new situations. On the other hand, if learning starts with abstract theory absent an experiential base, application of the theory becomes largely a game of plugging arbitrary values into formulas that "work", not because they accurately represent reality, but because they conveniently match the variables in the formula.

The rationale for project-centered education, then, is to counter the information-age mindset by providing our students a real-world context on which to base their understanding of engineering science. In doing so, we hope to develop an appreciation for "knowing", rather than simply "doing", and a more solid basis for application of engineering theory to new situations.

### **History, Timeline, and Organization of PROCEED**

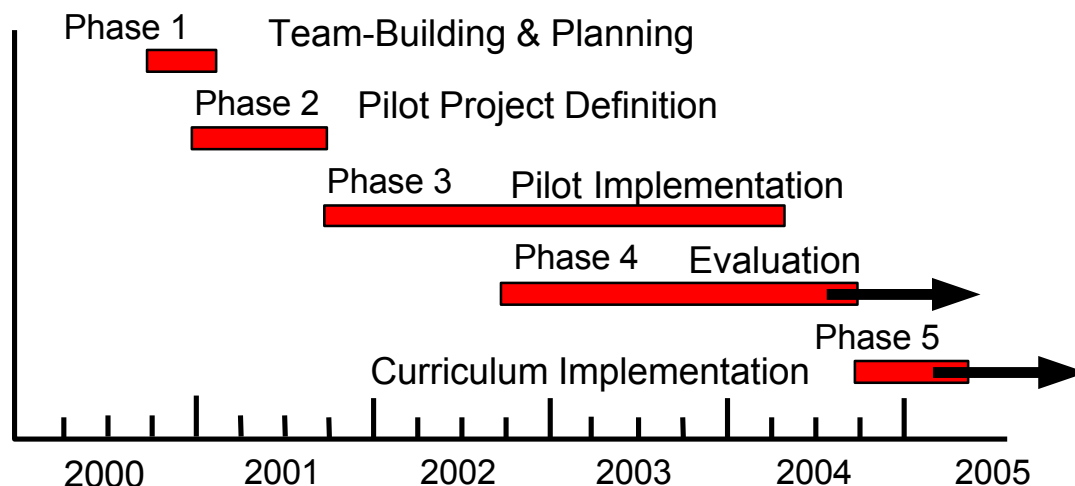
In the mid-'90s, substantial evidence began to emerge of the declining effectiveness of traditional learning methods in certain elements of our ME program, based in part on statistical information (e.g., low retention in the first two years) and in large measure on anecdotal results of course evaluations. This produced a general feeling of dissatisfaction on the part of many experienced faculty, and led to a series of informal brown-bag discussions in 1996 on what could be done to improve the situation. Out of these discussions came several curriculum and methodological changes which were implemented in the 1998-2000 catalog. These included:

- Consolidation of our separate freshman courses in engineering graphics and introduction to ME into a single course which centers instruction in graphics and concepts of engineering design around reverse-engineering of real devices (see Barr <sup>3</sup>).
- Converting our junior level course in machine elements, which was essentially a laundry list of topics in strength of materials and formulas for design of various components, into a project-centered experience, with theory and formulas being introduced as needed to reverse-engineer and extrapolate the design of real machine components.
- Converting our second thermodynamics course into a project-based thermal-fluid systems course in which theory topics are covered as needed to permit modeling of complex systems such as jet engines and cogeneration powerplants (see Schmidt <sup>4</sup>).

Based on positive results from these early efforts, a grant from Ford Motor Company was received in fall 2000 to broaden the scope of project-centered education to a department-wide effort. A second PROCEED grant from Applied Materials Corporation was received in 2001. The primary elements of this program include:

- Implementation of project-centered experiences in selected ME courses running throughout the curriculum from freshman through senior years ("just-in-time" theory).
- Redesigning and relocating "disconnected" lab courses to integrate them more closely with corresponding theory courses and reequipping related labs to provide a more flexible hands-on lab environment.
- Collaboration between faculty and practicing engineers from industry in the formulation and teaching of project-centered curriculum materials.
- Incorporation of computation, teamwork, and communication as common elements of courses to more accurately reflect the real environment of engineering practice.

The PROCEED initiative is being implemented over a five-year timeline, as illustrated in Figure 2.



**Figure 2: PROCEED Implementation Plan**

Phase 1 of PROCEED was officially inaugurated (i.e., the money was in the bank and the project was given a catchy name) in September of 2000. Over the next 6 months, a coordinating committee was established with broad representation across disciplines and ranks within the department. Members of the committee convened planning sessions of each of the various disciplinary areas to provide input on the extent to which curriculum in that area might be improved through project-centered activities and what approach might be most effective for specific courses. This grass-roots planning period was critical to the future success of PROCEED, not only for developing specifics of the program plan, but for building enthusiasm, across the board buy-in from faculty, and team spirit. In a major research university like UT Austin, where faculty are hard-pressed to fulfill their research missions, broad commitment to a time-consuming undergraduate curriculum reform effort was a major achievement. The planning period culminated in a full-day workshop in January 2001 which was attended by about two-thirds of the department's faculty. At this workshop, a set of desired curricular outcomes, similar but not identical to ABET's "a-through-k" outcomes, was established and an initial list of pilot projects was laid out.

Phase 2 was carried out during the spring and summer of 2001; thirteen pilot projects were defined in detail, actively involving about 20 faculty members. Budgets were established, initial corporate contacts were made, and supporting materials were prepared to permit pilot implementation in experimental sections of the respective courses in the 2001 fall semester.

Pilot implementation began with the 2001-02 academic year, and is continuing in 2002-03. Also during this period, an extensive evaluation process was initiated, both to provide formative assessment for ongoing improvement of individual courses and summative assessment of the effectiveness of the PROCEED program as a whole. This evaluation process is being integrated into PROCEED as a permanent element, and the assessment methods that are being developed will in the future be applied to both project-centered and conventionally-taught courses in the department. Most of the curriculum reforms now being piloted on a limited enrollment basis will be expanded during the 2003-04 academic year, and full-scale implementation is planned to begin in 2004 with publication of the next biennial catalog.

### **PROCEED Pilot Projects**

The PROCEED projects currently being implemented on a pilot basis cover the curricular spectrum from the first introductory ME course through the senior capstone design course. We should emphasize that the term "project-centered" is not meant to imply that an entire course is necessarily built around a single all-encompassing application. Projects may, in fact, take a variety of forms, ranging from short lab or computer simulation exercises coupled to a conventional homework set to major system design/analysis problems extending over a period of weeks. The common denominator is that the application must be real, actual hardware and data should be used when possible, and elements of teamwork and communication should be incorporated. Faculty and student contact with a practicing engineer familiar with the problem is desirable, and in the case of industrially-sponsored projects, essential.

Initiatives which focus on a specific course or group of courses in a given area include the following (note several projects may be grouped under one heading).

**Integration of CAD/FEA modules and rapid prototyping in freshman Introduction to Engineering Design and Graphics:** Faculty in our Graphics area have developed modules to teach students how to couple a 3D CAD model to a widely used finite-element package (COSMOS) for stress analysis and also to a simple rapid-prototyping machine which can produce visual prototypes. Assembly modeling and kinematic simulation modules are under development. Student projects include reverse engineering of industrially-supplied automotive components and robotic assemblies for handling of semiconductor wafers during processing.

**Integration of industrial case studies in Engineering Economics and Engineering Statistics and Probability:** Students in our junior-level engineering statistics and probability course are using a powerful statistical analysis package to evaluate manufacturing quality-control data supplied by an industrial partner. The purpose of the analyses is to pinpoint the origins of component failure.

A semester-long project centering around the design and production of a car to meet a particular market requirement has been utilized in our Engineering Economics course as the unifying theme to address such topics as capital and production cost analysis, time value of money, present worth, useful life, etc. As a spin-off of these upper-division initiatives, faculty have also produced short teaching modules that can be used in freshman courses to acquaint students with the relationship of economics and statistics to important engineering problems.

**Integration of labs and theory in core Materials Science and Engineering courses:** Faculty in the MS&E area have created a series of "reference modules" on various topics covered in our sophomore and junior-level core courses in basic materials science and materials processing. Modules include lecture presentations and examples, demo materials and video clips focusing on real parts and processes developed in coordination with industrial partners. Appropriate problem sets and lab exercises built around these applications have been developed.

In the junior-level materials processing laboratory course, a project is introduced during the first several weeks focusing on parts provided by an industrial partner. The project provides a frame of reference for a series of modularized laboratory experiments carried out throughout the semester that provide the students with experience working in teams as well as hands-on time using materials processing equipment.

A scanning electron microscope with analytical capability has been acquired as the centerpiece of a student materials-characterization laboratory. Use of the microscope in the two core courses mentioned above has been initiated and it is also being used in materials-related projects in our senior capstone design course and in undergraduate elective courses in the MS&E area.

### **Integration of labs and projects in core Thermal-Fluid Systems courses:**

As mentioned earlier, one of our early initiatives in project-centered education was the introduction of a junior-level thermal-fluid systems course to replace the traditional second thermo course. Most projects undertaken during the past several years have focused on computer modeling of complex systems, such as gas turbine/cogeneration powerplants, jet engines and associated aircraft performance, and heating/cooling systems for materials processing. One unique project entailed reverse engineering of a domestic refrigerator. Two identical refrigerators were purchased, one of which was maintained in running condition and instrumented so that students could acquire actual performance data, while the other was "sacrificed" to allow for observation and measurement of insulation, heat transfer surfaces, and compressor parameters. These data were used to model the system and predict power requirements, which could be compared with measured data and published specifications.

Two automobile-related projects have been implemented in our fundamental heat transfer class, one on cooling of an under-the-hood circuit board and the other on design of a radiator. These projects served as unifying themes for basic studies of conduction, convection and radiative heat transfer and were used in parallel with conventional textbook problems in the respective topic areas.

Two new laboratories in fluid mechanics and heat transfer, respectively, are being implemented in parallel with the corresponding fundamentals courses in these areas. Extensive redesign and renovation of the TFS labs is being undertaken to convert them from large single-purpose apparatus used mainly in the demonstration mode to flexible small-scale apparatus which can be economically replicated to foster a more hands-on experience. A number of simple "kitchen experiment kits" are being designed and fabricated to be used either as in-class demonstrations or take-home experiments.

**Introduction of computer simulation projects in Kinematics, Dynamics and Controls courses:** Faculty in the Dynamics and Controls area are implementing use of Working Model, a dynamic simulation software package, in our sophomore-level kinematics and dynamics course. Students use Working Model to perform parametric analyses related to textbook problem assignments and at the end of the course build a dynamic simulation model of an off-road bicycle. New project-centered modules are being developed to simulate automobile engine components.

We are also using Matlab and Sim-20, a Bond-graph modeling software package, in our junior-level dynamic systems and controls course to model noise, vibration and harshness (NVH) in automobiles.

### **Reverse engineering, redesign, and prototyping in Machine Elements:**

Our junior-level course in machine elements has been reoriented to teach machine element design through product emulation. Students reverse engineer an existing product, formulate and model design changes, and then recreate a functional prototype using LEGO Mindstorm kits.

**Expansion and upgrading of Student Reverse Engineering and Prototyping Laboratories:**

In years past, our senior-level design methodology and capstone design projects courses were largely taught "on paper". Students had little access to hands-on facilities to tear down and measure characteristics of existing mechanical systems or to build functional prototypes of their own designs. We are now equipping two student labs with a variety of tools and instruments to facilitate reverse-engineering studies, as well as wood, plastic, and metal-working equipment for prototyping. The availability of this lab has added a significant dimension to our design courses, as well as upper-division electives and independent projects courses.

In addition to the course-centered initiatives described above, several cross-curriculum projects have been undertaken which support the overall PROCEED effort.

**Videoconferencing to support student and faculty interaction with engineers in industry:**

The costs of travel and lost time can be a major obstacle to frequent interaction between faculty, students, and industrial sponsors, a key element of the PROCEED program. To help overcome this obstacle, a freestanding videoconferencing system has been installed in a large conference room equipped with both ethernet and ISDN communication lines to permit dialup videoconferencing with virtually any industrial or academic facility in the world. The system is portable and can easily be moved to other rooms in the building which have the necessary communication infrastructure. A distance learning classroom with a capacity of 35 students is also equipped for videoconferencing, and plans are in the works for similarly equipping a 100 seat lecture room. This will give us videoconference capability ranging from small project groups to large classes.

**Development of a web-based student portfolio system:** Media professionals in our Faculty Innovation Center, working with faculty and students, have developed a web-based electronic portfolio system which permits students to display the work they have done throughout their project-centered academic careers. The system consists of a preformatted template with a very user-friendly interface which allows students to easily create and update portfolios; it also includes provisions to allow student control of access to portfolios. These portfolios will provide a valuable added resource beyond transcripts and resumes for students to use in presenting their capabilities to prospective employers and graduate schools.

**Web-based learning modules on Engineering Ethics, Professional Responsibility, and Technical Communication:** Faculty in our Technical Communication and Legal/Ethical areas have collaborated to produce a series of web-based modules that can be used on an as-needed basis for a variety of project-centered courses throughout the curriculum<sup>5</sup>. Modules have been prepared on global and social responsibility, research ethics, scholastic dishonesty and plagiarism, working in groups, and writing executive summaries. Additional modules are currently in development.

**Evaluation and assessment of project-centered learning:** Assessment is a core element of PROCEED, both for real-time improvement of ongoing courses and long term evaluation of curricular design and teaching methodologies. We have engaged a full-time specialist in this area,



with education and experience both as a practicing mechanical engineer and as an educational designer/evaluator, who is developing a variety of assessment tools for project-centered courses <sup>6</sup>. These tools are being refined during the pilot phases of PROCEED and plans are to implement them on a department-wide basis during the 2003-04 academic year.

### **Implementation Issues and Challenges**

PROCEED represents a significant departure from traditional engineering educational methodology, and as such there are many issues to consider and challenges to overcome. The first and foremost question is "Does project-centered education work better than traditional lecture/problem methods in engineering?" There is a substantial body of research literature in the domains of K-12 science education and medical education to support the thesis that project-centered education (or more commonly "project-based learning") substantially improves long-term retention and "deep understanding" (the ability to extrapolate scientific knowledge to subsequent learning experiences and new situations) (see, for example, Barron et al <sup>8</sup>, Blumenfeld et al <sup>9</sup> and Williams <sup>10</sup>). Relatively little hard data is available specific to project-based engineering education; while it is reasonable to presume that similar benefits might accrue, this has yet to be proven conclusively. Preliminary indications, based on the limited sample of course evaluations and graduating student exit interviews we have conducted since initiating PROCEED, seem to be favorable from a student-satisfaction point of view. Obviously this is a rich field for further research and we plan to pursue this issue in our continuing assessment studies.

Another issue is workload for both students and faculty. Project-centered education is, by its very nature, labor-intensive; indeed, it can be argued that one of the central motivations for challenging students with open-ended problems is to break the "information-age mindset" which assumes that a "correct answer" to every problem can be obtained in a matter of minutes. In the PROCEED environment, mistakes and blind-alleys can be among the most valuable learning experiences, since they demand contemplation and reflection. On the faculty side, it goes without saying that lecturing from a well-worn set of notes and using the excellent resources supplied with standard textbooks is much less demanding than formulating new projects and counseling with individual groups of students to respond to their unique problems. Where is the cross-over between time well-spent and time wasted for both students and faculty? We cannot presume to answer the question at this point, but hope that good answers will emerge out of our experience with PROCEED.

Every project-centered course entails a tradeoff between time spent on broad coverage of a greater number of topics and time spent on application of fewer topics to realistic engineering problems. There is no simple formula which applies across-the-board; it is clear that some courses demand a more traditional topic-centered focus, while others, particularly those at the more advanced level, offer more flexibility to substitute depth for breadth. As we implement and evaluate PROCEED, we hope to refine our ability to effectively balance these competing objectives.

Organizing effective teams, teaching teamwork skills, and allocating credit for team-based work is a significant challenge in PROCEED. Fortunately, the literature offers some guidance in this area (e.g, Jensen & Wood <sup>11</sup>). As more faculty in our department become engaged in this mode of teaching we are working together to formulate best-practices on how to implement team-based learning.

Other challenges include how best to organize our interactions with industry, how to handle the logistics of massive numbers of students engaged in this more personalized learning style as we move toward full-scale implementation, and how to cover the costs of both initial development and sustained implementation. In this last category, we have been fortunate to obtain financial support from key industrial partners to get PROCEED off the ground. Our ability to expand and sustain this support will depend to a great extent on how successful PROCEED is in producing engineers of exceptional capability who can return the investment of our sponsors.

### **Conclusion**

PROCEED is a work in progress which we believe has the potential to substantially enhance the learning experience, technical competence, and marketability of our graduates. The knowledge, skills, ethics and attitudes which we are trying to instill are prerequisites for leadership in the professional world. We hope that this paper provides some insight into our motivations for undertaking the PROCEED program and the methods we are using to implement it in a large research-oriented university. As we progress in this process, we look forward to reporting both our successes and our failures as our contribution to the continuing quest for the best in engineering education.

### **References**

1. Frand, J. (2000): "The Information-Age Mindset: Changes in Students and Implications for Higher Education", Educause Review, September/October 2000.
2. Kolb, D. (1984): **Experiential Learning: Experience As the Source of Learning and Development**, Prentice-Hall, Englewood Cliffs, NJ.
3. Barr, R., P.Schmidt, T.Krueger, and C.Twu (2000): "Introduction to Engineering Through an Integrated Reverse Engineering and Design Graphics Project", J. Engineering Education, 89 (4).
4. Schmidt, P.S., J.Jones, G.Vliet, and T. Jones (2003): "A Project-Centered Approach to Teaching of Thermal-Fluid Systems Analysis and Design", Proceedings of the 2003 ASEE Annual Conference, Paper 2003-460.
5. Hart, H. and O.C. Moore (2002): "Developing Instructional Modules on Engineering Ethics", Proceedings of the 2002 ASEE Annual Conference, Paper 2002-2123.
6. Jones, T.L. (2003): "Self-Reported Instrument for Measuring Student Learning Outcomes", Proceedings of the 2003 ASEE Annual Conference, Paper 2003-920.

7. Jones, T.L., (2003): "Conveying Instructor Expectations in a Project-Centered Course", Proceedings of the 2003 ASEE Annual Conference, Paper 2003-619.
8. 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).
9. 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).
10. Williams, S.M. (1992): "Putting Case-Based Instruction into Context: Examples from Legal and Medical Education", J. Learning Sciences, 2 (4).
11. Jensen, D. and K. Wood (2000): "Incorporating Learning Styles to Enhance Mechanical Engineering Curricula by Restructuring Courses, Increasing Hands-On Activities, and Improving Team Dynamics", Proceedings of the ASME International Congress, November 2000. (ASME Curriculum Innovation Award Paper, April 2001).

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