Multi-Electronic Media Classroom for Computer–Aided, Problem-Based Learning for Improved Chemical Engineering Simulation, Analysis, Control and Reactor Design Education

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Abstract — *A new paradigm is rapidly developing, with the increasing electronic sophistication of teaching methods and classrooms, for problem-based learning (PBL). This paper describes the study being performed in the Chemical Engineering Department at Lamar University to integrate best practice pedagogy with computer-aided modeling and simulation into a PBL educational program. The pedagogical principles are being examined in both undergraduate core courses and graduate courses. A new path-finder course, Computer Aided Modeling and Simulation (CAMS) is being introduced to prepared students for the new learning technologies and to introduce future learning needs. DMCPlus advanced control software, Aspen Plus and Pro II are examples of the software being exploited. A prototype modern classroom is being used to test pedagogical principles and will be discussed in terms of the pedagogical objectives of PBL. From teaching and learning experiences with the prototype classroom, a new classroom has been designed to optimize the PBL learning process.*

INTRODUCTION

This paper results from a National Science Foundation funded Course, Curriculum and Laboratory Improvement Program [1] to adapt and implement computer aided problem-based learning (CA-PBL) in Chemical Engineering education at Lamar University using computer technology. The project integrates computer-aided modeling and simulation into the courses and curriculum in undergraduate and graduate education. It seeks answers to: what are the best strategies for integrating modeling and simulation into the curriculum, courses, and the laboratory, how can computer related tools promote Integrative strategies for research and learning in the context of PBL, what are the best modeling and simulation tools and techniques available for teaching chemical engineering and providing the student with the understanding, appreciation, and skills to use the techniques properly for specific problems, what are the best ways to evaluate the success of the teaching strategies, and what classroom architecture and innovations are needed to support this integration. This paper addresses these questions.

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Problem Based Learning, PBL

PBL [2]-[12] is broadly defined as an educational approach to structuring curriculum and courses that involves facing students with problems that provide a stimulus to learning [2]. It has the following attributes [3]:

- Learning is student centered.
- Learning occurs in small student groups.
- Teachers are facilitators or guides.
- Problems form the focus and stimulus for learning.
- Problem-solving skills developed through problems
- New information is acquired by self-directed learning.

PBL is evolving in engineering education [4] by the incorporation of computer-aided modeling and simulation into the process [5]. Smith has incorporated computer based modeling technology into a problem-based freshmen course at the University of Minnesota [6]. Problem based learning is particularly suited for engineers since it parallels the scientific method: identification of the problem, definition of the problem, formulation of hypotheses, projection of consequences and testing the hypotheses [7]. The PBL process is [8]:

- organize prior knowledge and identify the nature of the problem
- students pose questions about what they need to delineate to gain understanding
- students formulate a strategy solve the problem and identify the methodology and resources they need.
- Students continue to gather and process information as they work to solve the problem.

The instructor in a problem-based learning experience should identify a problem suitable for the students that is connected with the context of the students' world so that it presents authentic opportunities, organize the subject matter around the problem, not the discipline and give students responsibility for defining their learning experience and planning to solve the problem. The instructor creates learning teams to encourage collaboration. Finally, students are expected to demonstrate the results of their learning through a product or performance [9]-[12].

Simulation and Modeling

Commercial modeling software packages such as (but not limited to) Breeze, Epcon, HYSYS, AspenPlus, ProII with ProVision, Control Station, DMCPlus [13], PolyMath and MathCad are being used not as “black boxes” but are being used to enhance the fundamental understanding of the chemical engineering principles on which the modeling and simulation tools are based. This effort is being supported by use of university-developed modules such as the Purdue Computer Simulation Modules, the Michigan Modules, Chemical Reactor Design Tools, and other software packages. In addition, visualization, [14], virtual reality and hypermedia tools are being accessed as needed [15]-[17]. Progress in this project has been reported [18].

CLASSROOM INNOVATIONS

Classroom design for higher education has been traditionally conservative with the legacy of the traditional science based, front facing classroom as its base. Problem based learning demands very flexible classroom designs [14]-[16] including: a level floor, movable seats and tables, no central seminar table, easy access to writing boards and a design that still allows instructor focused lecturing in special events. Adding electronic based multi-media and computer aided learning methods raises additional demands on the design architecture. Traditional arrangements of computers on tabletops in long rows in computer classrooms totally defeats problem based learning.

CCLI Prototype Classroom

Group Operation: After PBL groups form, there is a need for the instructor to meet periodically with each, for mentoring and tutoring. These meetings can be face-to-face, by conference call, by chat room or web meeting. The dominance of information collection and processing in the PBL process is ideal for the use of electronic resources for collection, compilation and utilization of this information. In the PBL process being used in Chemical Engineering the information generated by a particular group is generally stored and made available to the class in the form of Power Point Presentations. These are placed on the Class’s web page site and can be accessed by the entire class students. Students also maintain individual folders on the web site, which allows monitoring of each student’s contribution to the information manipulation. Also, it is quite common to have the groups functioning in the classroom and this is where proper classroom design in paramount.

Classroom Architecture: A small prototype computer based classroom [18] to test the principles of CA-PBL has been developed. The classroom has the following layout (Figure 1) and equipment: It is served by a CISCO Aironet 350

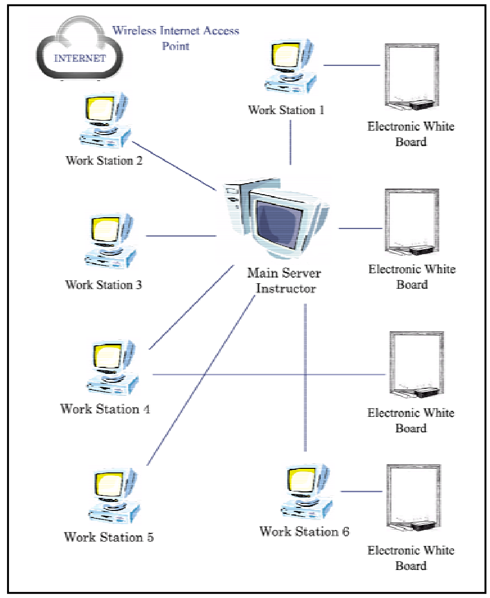


FIGURE. 1
PROTOTYPE MULTI-ELECTRONIC MEDIA CLASSROOM

Wireless Networking System. The main server for the instructor is a Gateway E-4600 SE with Windows 2000 Server. The students have 6 Client Computers - Gateway E-1600 SE with Windows 2000 Professional. There are four electronic white boards 4’x 6’. In addition there is a Toshiba TPL 671 LCD Projector and a Webcam.

Multimedia Electronic Projector with Overhead Camera and WebCam: Such a projector as shown in Figure 2 is an important transitioning unit in the classroom since it allows textbook materials and transparencies to be projected. This allows beginning instructors with traditional materials to use the classroom - essential to getting established faculty to actively participate in PBL. WebCams are used for videoconferences with individual groups from

FIGURE. 2
TOSHIBA TPL 671 LCD PROJECTOR

remote locations. It also allows material to be digitized and transmitted to the class by e-mail or other digital recording media.

Electronic Smart Board: The electronically smart white boards allow the instructor and PBL groups to use projection screen support-to make the white boards as touch-sensitive projection screens by connecting to PC and LCD projector, to save everything written or drawn in various colors on the board instantaneously to PC's or storage media, to send e-mails, or posts notes directly to the department web site to share with colleagues world-wide, and to involve real time teleconferencing with remote participants.

Paperless Design

Hypermedia in the classroom has to a large extent removed the burden of students' manual note-taking since virtually all materials can be electronically based or electronically captured and e-mailed to the students. This frees the students to concentrate on the information being discussed in class and aids considerably in promoting PBL working groups' activities. It allows students to become more involved in class discussions and in interacting with the instructor. The availability of the electronic white

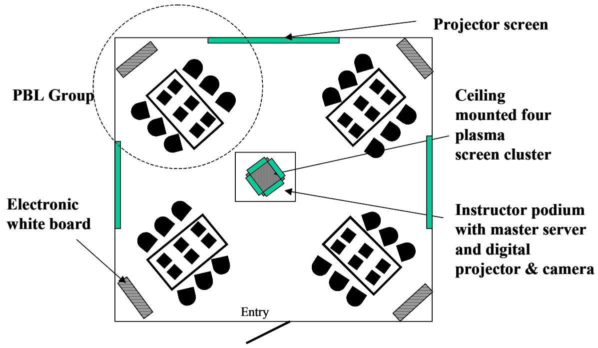


FIGURE. 3
PROPOSED MULTI-ELECTRONIC MEDIA CLASSROOM

boards for each PBL group allows capture of written documentation of discussions and allows the instructor to review all materials discussed by each group. The era of the paperless classroom is today a reality.

A New PBL Computer Based Classroom

The use of the prototype electronic classroom described above has resulted in the design of a new classroom (Figure 3) that will be incorporated in our program for engineering education. It goes beyond the "conventional" electronic classroom [19] and adds a dimension of separation of groups, yet maintains the unity of an instructor-controlled classroom. It requires that the instructor be located in the center of the classroom with a podium containing a master server, web camera, and digital projector with camera. Located above the podium will be four plasma computer screens that are connected to the master server and can be controlled as a unit or separately to provide visual information to each group. Each PBL group will have six computers and an electronic whiteboard. These will be used in-group discussions. The master server will monitor all white boards and all computers. This will allow instructor participation in the group activities.

CURRICULUM MODIFICATION

Introduction of CA-PBL is requiring the redesign of the Chemical Engineering Curriculum Course flow is shown above. A new course has been prototyped and added in the second year. Computer-Aided Modeling and Simulation (CAMS) is a "Path-finder Course" This prototype course integrates problem-based learning (PBL) pedagogy into the chemical engineering curriculum with an implementation of computer-aided modeling and simulation packages. CAMS, introduces CA-PBL in the sophomore level and concludes at a senior course of Advanced Analysis.

CAMS introduces students to two types of computer packages: mathematical packages (MathCad and POLYMATH) and simulation packages (Aspen and ProII). During the first six weeks of class, the students use the mathematical packages to solve math problems that typically arise in upper-level chemical engineering classes, including regression (both linear and nonlinear), nonlinear equations, and systems of ordinary differential equations. The remainder of the semester is devoted to familiarizing

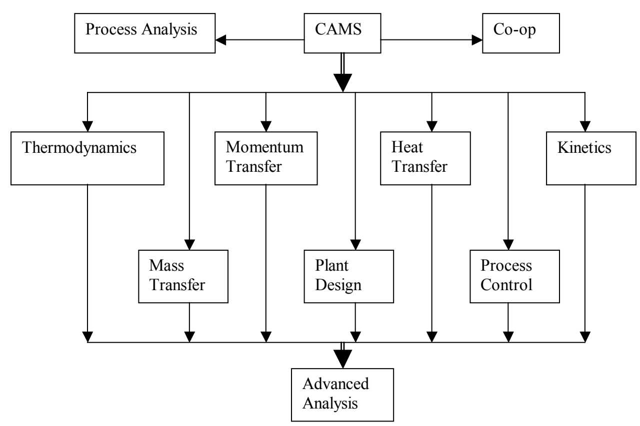


FIGURE. 4
CURRICULUM FLOW PATTERN WITH CAMS AND

the students with the simulation packages. Since these sophomore students have not yet had any chemical engineering courses (except the material and energy balance class, which they take concurrently), some time is spent describing the theory behind such common unit operations as flash drums, heat exchangers, chemical reactors, distillation columns, etc., as well as the theory behind each package's solution algorithm. Details are left to later upper-level classes, after the students have been introduced to the required fundamental theory. However, problems in several junior and senior courses are given in this class and solved by computer packages.

Starting CAMS teaching at a stage as early as the sophomore level is quite new in chemical engineering curricula. However, after two and a half years experimenting, the NSF-CCLI implementation project finds that the advantages are substantial. The first advantage is to help students in co-op program and in the Process Analysis Course (Material and Energy Balance). Most of our co-op students use one of the Computer Aided Modeling and Simulation packages (such as ASPEN, PRO II, and HYSYS) during the co-op time period. CAMS prepares them early enough that they are able to move into the work situation quickly to solve practical problems in industry. Returning co-op students have a "problem based learning" pedagogical mind-set and more appreciation learning the fundamental principles in junior/senior engineering basic courses. This helps to pave-the-way for PBL pedagogy in the chemical engineering curriculum. CAMS is a pathfinder for PBL and the curriculum flow shown in Figure 4.

The NSF-CCLI implementation project has found that the co-op students can learn the fundamental principles more effectively than the non-co-op students. This could be a difference between the learning pedagogies of science and engineering education. In other words, the engineering students feel the need to learn fundamental principles in order to solve problems.

Another advantage of CAMS is to prepare the students for the chemical engineering sophomore (Process Analysis), junior (Thermodynamics, Momentum Transfer, Heat Transfer, and Kinetics) and senior (Mass Transfer, Plant Design, and Process Control) courses in problem based learning with an implementation of computer aided modeling and simulation. CAMS teaches the students to do a process simulation for the units of Mixers, Separators, Heat Exchangers, Columns, Reactors, and Pressure Chargers. These units are the applications of Process Analysis, Momentum Transfer, Heat Transfer, Mass Transfer, and Kinetics. Besides, the selection of the thermodynamic models prepares the students to learn a non-ideal mixture of chemical compounds that will be studied in Thermodynamics.

With CAMS preparation, students are assigned problems closer to the real world. The instructors can encourage the students to experiment with different operating variables to understand fundamental principles. The purpose of this project is to develop the material in this prototype course, CAMS, so that the advantages of learning in the chemical engineering program can be realized.

Kinetics

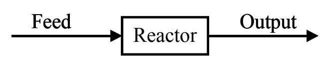
The problem given in CAMS is a reactor design problem to handle an esterfication of acetic acid with ethanol to produce ether acetate. The temperature, the pressure, and the components of the feed stream are given, it is required to find the output concentration if the reactor type, size, and condition are specified. A description of this problem is given below:

$$\text{Ethanol} + \text{Acetic Acid} \underset{k_r}{\overset{k_f}{\rightleftarrows}} \text{Ethyl Acetate} + \text{Water}$$

where the reaction rate constants are given as

$$k_f = 1.9 * 10^8 \exp[(-5.95*10^7 \text{ J/kmol})/RT]$$

$$k_r = 5.0 *1\ 0^7 \exp[(-5.95*10^7 \text{ J/kmol})/RT]$$

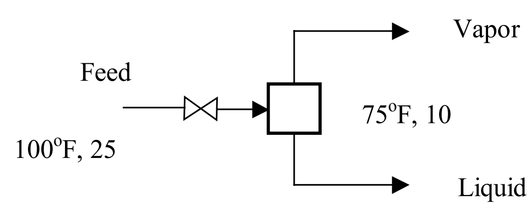


At 1 atm and 70°C
Water: 8.892 kmol/hr
Ethanol: 186.59 kmol/hr
Acetic Acid: 192.6 kmol/hr

What will be the output concentrations for a Continuous Stirred Tank Reactor (CSTR) with a reactor holdup V=0.14 m^3 at 70°C and 1atm? The students will learn quickly that there are several different reactor types available in the simulation packages. It is fairy easy to explore the performances of different types of the reactors, but the learning of the fundamental principles has to be waited until junior Kinetics class.

Mass Transfer

The problem given in the class is an equilibrium flash vaporization. A feed stream flowing at 1000 lb/hr contains an equimolar mixture of n-butane, n-pentane, n-hexane, and n-heptane at 100°F, 25 psi. The feed enters a flash drum maintained at 75°F and 10 psi. What is the flow rate and



composition of the vapor and liquid streams leaving the flash drum? What students can learn from this example are (1) equilibrium versus non-equilibrium flash vaporization, (2) isotherm versus adiabatic flash vaporization, and (3) pre-heat versus reduce pressure flash vaporization. This is a good example that should pave the way for students to learn thermodynamics, mass balance, and energy balance.

Basic Control

Control Station [20] training software is an excellent tool for learning basic/ advanced control schemes, controller design, and controller tuning in a workshop environment. The software was installed in the PBL/CCLI room to allow group discussions. Discussion sessions were held after workshops to evaluate students' learning. Students reported a better grasp of the dynamics and PID control fundamentals and they appreciated the hands-on learning experience.

Advanced Control

DMCPlus, [21], is an industrial standard for multivariable, constraint control and is the most widely used advanced control software in petroleum and chemical process industries [13,22]. It is incorporated in the senior Process Control II Course (CHEN 4332). DMC Plus compliments HYSYS and Atlantic Simulation currently included in the Process Control Lab (CHEN 4150) [23]. We use the crude fractionator as an open-ended project to learn model identification, LP (Linear Programming) cost optimization, and DMC controller tuning. The fractionator consists of a 5x3 multiple inputs multiple outputs (MIMO) system plus feed-forward scheme. All the step responses can be displayed on the console as in the plant control room. The project culminates with student oral presentation of their DMC solutions and evaluation of the technical merits by their peers. The students develop a broad view of the "real-world" plant control structure and understand the relationship between the DCS (distributed control system) regulatory control and the DMC advanced control. They also realize the functional relationship between the real-time optimizer (e.g., RT-Opt, ROMeo) and the DMC advanced control system.

Advanced Analysis

Finally, Advanced Analysis, a last semester senior capstone course, uses the CCLI classroom to fully implement CAMS and the CA-PBL pedagogy. In the Advanced Analysis, chemical engineering problems are given to the students at least one week ahead for the students to study and understand. In the class students have to use the fundamental principles learned from the courses as shown in the above chart to set up the system equations or the inputs for the CAMS packages. The instructor may initiate the questions and when the students answer the questions the others may challenge that answers. The instructor may give minimum necessary corrections in order to encourage the discussions. Through this problem based learning pedagogy, students can concentrate more than a traditional teaching method because of the participation. We are expecting that the PBL pedagogy can be used effectively in the last semester Advanced Analysis class because all the principle courses have been taught.

To fully use the PBL pedagogy, a description of the problem must be distributed to the students days or even one week before the class discussion. This gives time for the students to understand the problem, search for references, and prepare for the class discussion. A simple problem selected from Jenson and Jeffreys (23) is:

A tank contains 2 m^3 of water. A stream of brine containing 20 kg/m^3 of salt is fed into the tank at a rate of 0.02 m^3/s. Liquid flows from the tank at a rate of 0.01 m^3/s. What is the salt concentration in the tank when the tank contains 4 m^3 of brine? Plot the salt concentration and the volume versus time.

Students are encouraged to participate in the modeling of the system by starting with first principles, material and energy balance. To make modeling possible, the following typical assumptions are required: 1) Will the liquid volume be changed after mixing? 2) Will the temperature be the same after mixing? 3) Will the brine concentration in the outlet be the same as that in the tank?

The electronic boards, allow the students to concentrate on the discussion of the modeling process bynote taking. Instead, they can. The instructor gives only guidance but not the "solution". Both sides of an assumption should be explored and discussed, and a reasonable assumption can be recognized but not assigned. Because of participation, the students have better understanding of the problem than the traditional one-way lecture.

To solve system equations, the class splits into two groups, one group uses computer packages such as PolyMath while the other uses analytical methods. Both numerical and analytical solutions can be presented and compared. A question about truncation error and round-off error initiates a discussion where the instructor is prepared to give guidance if the students are not familiar with the Runge-Kutta numerical method.

The students can present their results through a computer network with the LCD projector again allowing open discussion. For this example, the solutions are simple: the brine concentration increases exponentially and then gradually approaches the inlet concentration while the volume increases linearly with time. For other more complicated system, the discussions of the results are very involved. Most of the students find that it is very helpful to understand the system behavior through the discussion of the result. This part is called the interpretation of the results.

Another part of the Advanced Analysis is safety case study. The class separates into three groups for the study of the following three cases: 1) Piper Alpha – Spiral to Disaster, 2) Phillips 66 Company Explosion and Fire at Pasadena, Texas and 3) Methacrylic Acid, Tankcar Explosion and Methods of Safety Handling, from the Safety and Chemical Engineering Education (SACH) Division in the American Institute of Chemical Engineers (AIChE).

The material including video and CD were distributed to the group one week before the group final presentation. The students watched the video/CD, discussed the events, and then analyzed the safety considerations. The students used the smart boards for group discussion. The instructor monitored the group discussions from the instructor's station but did not interrupt their discussions. All the group discussion material was saved into the computer without typing. We find these types of "problem-based" and "student-centered" discussions are very effective as every student is challenged to participate and contribute to problem solving.

CONCLUSIONS

CA-PBL poses challenges for administrators, educators, students and classroom designers. The change from instructor-centered to student-centered, computer aided PBL in higher education is well worth the effort. However, CA-PBL classrooms must be carefully designed to meet the pedagogical objectives and may require curriculum change. In the case of CA-PBL, the modern multi-electronic classroom is essential for optimization of the PBL process [1]-[12]. CA-PBL inspires a new pathfinder course CAMS in the ChE Curriculum.

ACKNOWLEDGEMENT

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