# HIGH-PERFORMANCE LEARNING ENVIRONMENTS

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Considerable research has been directed toward identifying educational methodologies that are effective and efficient.[1-3] Growing evidence suggests that the most successful approaches place the instructor in the role of facilitator, rather than in the position of "chief eminence" in front of the classroom.[4-7] Moreover, optimal facilitation of learning entails structuring the style, format, and day-to-day activities of the course using a variety of proven practices, such as those listed in Table 1.[1,2,8,9] We collectively call these strategies "modern" approaches to learning.

We have been developing a powerful methodology that strongly and cohesively exploits these modern learning approaches. In particular, it places responsibility squarely on students for their own learning. While most previous efforts have shown one or more of the three "basic" levels of modernization (problem solving, communication, and teamwork), we have added two more: experimental prototypes and industrial contacts. Together, they create active-collaborative learning environments we call "High-Performance Learning Environments" or "Hi-PeLE." This *non-lecture* based environment encourages students to become efficient and independent thinkers; it also promotes confidence in their knowledge and ability to solve complex problems at a level that is not observed in students where the environment is not used.

Further, we believe that using this methodology offers two valuable by-products. First, it helps ease students' transitions from the classroom setting in the early stages of the chemical engineering curriculum to the laboratory environment of the later stage. Second, it helps ease the transition for faculty to adopt and retain modern learning approaches in the classroom setting. This "dual" role of Hi-PeLE helps tremendously to modernize many aspects of the chemical engineering curriculum and, in addition, we believe it promotes an efficient approach to developing a *community of learners* within a department.

## UNIT OPERATIONS LABORATORY

The concept of unit operations was introduced at the onset of the evolution of the chemical engineering discipline early in the twentieth century. Accompanying this idea was the introduction of the unit operations laboratory, a traditional core element of the chemical engineering curriculum. Indeed, the course is so traditional that some faculty look upon it as a quaint relic of the past that is out of place in our modern times.

To be sure, the physical facilities at some universities may be old, with cluttered workspace, poor lighting, dirty floors, smelly chemicals, and mercury manometers. Nonetheless, we assert that a re-examination of the unit operations lab in the context of educational methodologies has value.[10] The reason is that this learning environment inherently uses a student-centered, hands-on approach; the activities are active, collaborative, and sequential.

Further, communication is multidimensional in the sense that students must communicate with peers as well as with teaching assistants, lab technicians, and possibly other instructors. They also use a variety of formats to communicate, such as written reports, oral presentations, calculations, procedures, data tables, diagrams, and graphs. They may also have to deal with vendors to check or find equipment specifications for lab devices.

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In the unit operations laboratory, a student's success heavily depends on the success of the team.[11] The fact that students must learn how to program experimental activities to maximize time utilization, to understand equipment failure, and to deal with experimental errors brings a dynamical, open-ended component to the learning environment that is impossible to reproduce in "dry" classroom environments.

In short, we claim that the traditional learning environment of the unit operations laboratory is a subset of modern approaches to engineering education, at least as they are defined in Table 1. In other words

$$\text{"Traditional" Lab Work} \in \text{"Modern" Learning Approaches} \qquad (1)$$

and, therefore, the unit operations laboratory offers the most appealing features that a modern engineering educational environment must display.

Since its inception, the technologies of the unit operations laboratory have changed. But at its core, its preeminent status as an educational paradigm for chemical engineering is one of the most clearly defined invariants in chemical engineering instruction.

## TRADITIONAL CLASSROOM ENVIRONMENT

In contrast, another well-defined invariant over the years in chemical engineering education is the way that classroom instruction has been conducted. It has been based upon lectures, lectures, and . . . more lectures. It is typified by a non-active, non-collaborative approach that leads to low efficiency in student learning. We take the position that lecture-based approaches are of little help in developing the student as an independent thinker and creative engineer and, in general, that they are not considered among the modernization techniques for learning approaches. Others have a different view.

The traditional classroom is dominated by one-way communication: information flows from the high "wisdom" of the lecturer to the students—all without the possibility of immediate, meaningful feedback. The material is presented in a way (clean, well-organized, no mistakes, closed ended) that is far removed from reality. Moreover, babying students by spoon feeding lectures to them stymies their development in assuming responsibility for their own learning.

In short, we believe that

$$\text{"Traditional" Classroom} \notin \text{"Modern" Learning Approaches} \qquad (2)$$

**TABLE 1**
**Characteristics of "Modern" Learning Approaches**

- ► Active learning
- ► Sequential tasks
- ► Open-ended problems
- ► Bloom's Taxonomy
- ► Teamwork among students
- ► Multidirectional communication
- ► Student involvement with assessment
- ► Instructor as facilitator

**TABLE 2**
**Modernizing Classroom Learning**

- ► Short team exercises
- ► Brief team reports
- ► Team presentations
- ► Journal articles
- ► Facilitating class discussion
- ► On-line course materials
- ► Computer simulation –
  - Virtual experiments
- ► Modern textbooks –
  - Assist and enhance approaches

## HIGH PERFORMANCE LEARNING ENVIRONMENTS (HI-PELE)

Table 2 summarizes some of the techniques that can be found in the literature to modernize chemical engineering classroom instruction.[1-3,9] While they have proven valuable, we nonetheless assert that there is opportunity to do even better by confronting nature as part of the learning process.

There is no substitute for an actual experiment. Conducting a *hands-on* experiment provides a different perspective than lectures, textbook problems, or even computer *virtual* experiments. Things go wrong with experiments and, when they do, students have a chance to figure out why they went wrong. But even more important, experiments bring an element of excitement to the classroom.[12]

A learning environment can be built on the features of Table 2 and, in addition, take advantage of the learning qualities found in the unit operations laboratory. The approaches are complemented with other tools to create an environment that is rich with a high level of active and collaborative activities.[3] In fact, the mode of instruction is a multitask environment centered on student learning;[4] we have named this type of instruction mode "High-Performance Learning Environment" or "Hi-PeLE." (The acronym was selected because the soccer player Pele epitomizes high performance in the world's most popular sport.)

The Hi-PeLE construction is based on five tools: problem solving, experimental prototypes, industrial contacts, teamwork, and communication. The idea behind the methodology is that every activity is student driven and that the instructor functions as a facilitator or coach.[7] Furthermore, incorporating experimental prototypes and industrial contacts into a "classroom" course opens avenues for enhancing and reinforcing problem solving,[13,14] teamwork, and communication.

One obvious benefit of Hi-PeLE is a high level of student energy that occurs outside of the traditional classroom routine. There is hardly a moment when the students are passively following a detailed recipe of instruction. Rather, they acquire independence as they assume responsibility for their own learning, manage their own team project, and show off their skills.

A second advantage of Hi-PeLE is that it directly addresses many of the ABET criteria pertaining to Program Outcomes.[10] This benefit can be amplified by establishing a sequence of courses in the curriculum with Hi-PeLE, thereby providing students with successive opportunities to demonstrate and strengthen their knowledge and abilities in the desired areas specified by the Program Outcomes.

Hi-PeLE also helps instructors devise multifaceted, synergistic learning activities that span the entire range of Bloom's taxonomy of thinking skills.[15] In particular, by incorporating an experimental project into the classroom environment, as outlined in Table 3, students perform in a task sequence that fosters creativity.[7]

Finally, we have found that the Hi-PeLE methodology has been consistently appreciated by students in the courses where we have been developing this approach.[10]

## HI-PELE IMPLEMENTATION

Environments based on Hi-PeLE have been designed, developed, and tested in several courses at the College of Engineering jointly operated by Florida A&M and Florida State University, at Rose-Hulman Institute of Technology, and at Tennessee Technological University.[16,17] A full-fledged Hi-PeLE has been implemented for sophomore and junior courses in momentum transfer and in heat transfer. A special compressed version has been introduced in a two-week slice of our freshman survey course called "First-Year Engineering Laboratory," while a simpler environment has been adapted for our senior and graduate courses in reactor design. At Tennessee Tech, a senior-level transport phenomena elective and the required reactor design courses have been taught recently in a Hi-PeLE.

Table 4 summarizes the course outline for an introductory course in heat transfer. Four components of the Hi-PeLE are included; the fifth component, "communication," permeates all of the activities. Clearly, this outline departs considerably from a traditional course outline where the entire course focuses almost exclusively on problem solving. In Hi-PeLE, while an important portion of the course is centered on problem solving, four other components play a significant role in the student learning process. A brief discussion of these aspects follows in the paragraphs below.

***Problem Solving***[13,14] At the regular class meeting, students learn to apply the fundamentals of the course topics to solving problems. The instructor has the chance here to implement a variety of instruction modes—rather than just lectures, we recommend that instructors move towards active and collaborative activities[3] using the approaches in Table 2.

Using Hi-PeLE, student teams can bolster problem-solving skills by formulating problems related to their respective experimental prototypes. Here, the instructor can encourage student teams to develop open-ended problems in addition to the closed-ended problems they typically conceive. These student teams can then present their problems to the entire class, using a variety of modes. This type of activity can bridge all five learning tools. And, as students practice teaching one another, they assume responsibility for their own learning.

***Experimental Prototype*** This component anchors on-paper application of the fundamental principles of the course with hands-on equipment activity. The activity could be simple inspection of an existing apparatus or construction of a scaled-down, non-working model. We have observed, however, that students gravitate towards building an experimental prototype to conduct measurements that enable calculation of values of, for example, the overall heat transfer coefficient. The experimental prototype stimulates motivation (and, in turn, high performance) because students can create their own approach to bring a fundamental concept into action.

We identify topics for the experimental prototypes prior to the start of the course, gathering suggestions from other faculty members such as the unit operations lab instructor and from practicing engineers with substantial industrial experience. Example heat transfer topics for experimental prototypes are listed in Table 4.

While small projects can be assigned to individual students, we prefer to assign larger projects to teams of students. We try to have sufficient topics so that only one team is assigned to a given topic. This approach creates useful negotiation and discussion among the students—they must find a procedure to assign the topics in a fair manner.

During the first week of the course, students are told that the project will be for the entire semester, and that several intermediate milestones must be reached to ensure completion of projects by the end of the semester.[5] To further ener-

**TABLE 3**
**Incorporating Experiments into the Classroom**

- Introductory Courses
  - Fluid mechanics
  - Heat transfer
  - First-year engineering lab
- Paradigm
  - Unit operations lab
- Projects
  - Semester project involving experimental prototype
  - Student teams (3 members)
  - Each team assigned a different topic for project
  - 25% of course grade for assigned project
  - 25% of course grade for all class projects
- Task Sequence
  - Theoretical foundation
  - Historical background
  - Experiment conception
  - Interim presentation
  - Design equipment and experiment
  - Build a working prototype
  - Final written report
  - Final presentation forum (panel of judges)
  - Final exam on all class projects

gize student interest in the projects and their connection with fundamental principles, we alert them that the final exam will be based entirely on all the projects.

***Industrial Contacts*** This component provides students with a chance to engage directly in a "real" aspect of the profession while still in an academic environment. We have found that activities for this component increase student motivation and readiness for learning fundamental concepts. We have explored several types of activities for this component.

One option is to ask vendor representatives to visit the class for a workshop on selection criteria, price comparisons, and troubleshooting. The vendor representatives can supply extensive literature that illustrates the basic physics of the equipment, as well as pertinent articles from engineering magazines. So far, we have tried this approach for flow meters, control valves, and process computers.

Another approach is to invite a seasoned engineer to review a real case. We have had speakers cover condenser specification and bid review, distillation troubleshooting, and heat transfer in batch reactors. Students have been impressed when they realized that the concepts and equations were the same as the ones used in problem-solving exercises in the course.

**TABLE 4**
**Summary of Course Outline for Introductory Heat Transfer**

***A. Topics for Problem Solving***
1. Conduction: fundamentals in 1D, 2D with various geometries
2. Convection: temperature profile in 1D flow
3. Thermal convection: open and closed systems
4. Radiation: Fundamentals and applications (solar heaters, furnaces, combustion)

***B. Team Projects for Experimental Prototypes***
1. Condensers
2. Evaporators
3. CSTR - heat transfer aspects
4. Tubular reactor – heat-transfer aspects
5. Plate-and-frame heat exchangers
6. Heat-transfer coefficient - measurement methods
7. Boilers

***C. Suggested Activities for Industrial Contacts***
1. Visit and inspect equipment in the unit operations laboratory
2. Visit local companies to inspect heat-transfer equipment
3. Contact vendors for equipment specifications and design calculations
4. Discuss project issues with the instructor of the unit operations laboratory

***D. Suggested Preliminary Activities for Teamwork***
1. Pick team members
2. Discuss and assign among all teams the suggested projects
3. Formulate and write a Code of Cooperation for team
4. Develop a tentative meeting schedule, stating objectives for each meeting

***E. Assessment***
1. 30% - Mid-term exams
2. 10% - Homework
3. 10% - Course folder
4. 15% - Poster presentation on assigned project topic
5. 10% - Written report on assigned project topic
6. 25% - Final exam covering projects of all teams

We have found that the most effective mode is one in which the students take the initiative to consult with sales personnel and technical experts at equipment vendors, to tour chemical plants, or to visit engineering construction firms to check equipment functionality, specifications, and availability in connection with their project for an experimental prototype. We also encourage students to scour the library and the internet for information (*Perry's Handbook* is not enough).

***Teamwork*** The course may be the first significant opportunity for students to work in teams in the chemical engineering curriculum, so we promote classroom discussion on the roles and responsibilities of team members and on the risks involved in the selection of team members. Further, in order to help class members to become acquainted with one another, each student prepares a written resume on his or her educational objectives, work skills, and personal style and preferences. Having laid this groundwork, students are well positioned to select their team members early in the course.

In our pilot studies of Hi-PeLE, we found teams of three members to be most effective. This size was sufficient to provide activities that enabled students to gain skills in project management and teamwork in an engineering context. The number of students participating in a team may affect significantly the dynamics and efficiency of a team.[11]

***Communication*** Hi-PeLE provides for a multidimension environment (*i.e.,* communications at various levels) for the students to practice. For example, they work in teams where information is exchanged. They also need to discuss guidelines for projects with the instructor and to inspect lab equipment in the unit operations laboratory or industrial sites. Furthermore, there is written communication in preparing progress reports and the final report for the experimental prototype.

While different types of implementations are possible in a Hi-PeLE, [16-18] we have frequently used a strategy based on working the fundamental aspects of a subject in "classroom activities" mode and placing the "applications" on the team-based efforts. Most of the activities related to team-based efforts are handled in a weekly optional recitation session for which we have a regular TA for grading purposes. Therefore, the manpower requirements are very similar to those in traditional approaches. In addition, all the experimental prototypes were identified and developed by students with "home-made" materials and devices.[17-18] Most of the projects can be completed for $50 to $100. It is useful to note that the training and the process of applying the ideas were more important than a "finished product"—this emphasis would change if the applications were part of a design course. Students were encouraged to consult other professors in the department, but these were "coached" beforehand to advise, but not solve, the problems for the students. This is an important aspect of the dual role of Hi-PeLE mentioned in the introduction section. Finally, selection of the students for the teams was conducted by using a functional-based approach[19] where the students are at the center of the selection process.

## ASSESSMENT

Among the objectives we set for the development of a Hi-PeLE, we wanted to increase students' motivation to learn fundamentals, to enhance their habit to learn (independently) the necessary material to attack the solution of a given problem, and to augment their ability to apply fundamental principles to practical applications, as well as to increase their confidence and readiness to solve complex tasks. In addition, we hoped to observe these characteristics as the students worked in the UOL, *i.e.*, before they exited to the work force. The learning environment was assessed by using a multi-tool approach[16-18] that included: a) mid-terms and a final written assessment, b) presentations (either oral or poster) with external judges, c) a debriefing session with judges, d) the assessment (by the instructor) of written reports, and e) the randomly selected interviews with students during and at the end of the course. In addition, at Rose-Hulman, a "peer review" assessment was used to monitor individual contributions and overall team progress and at FAMU-FSU an intra-course observation of students in the UOL was conducted.

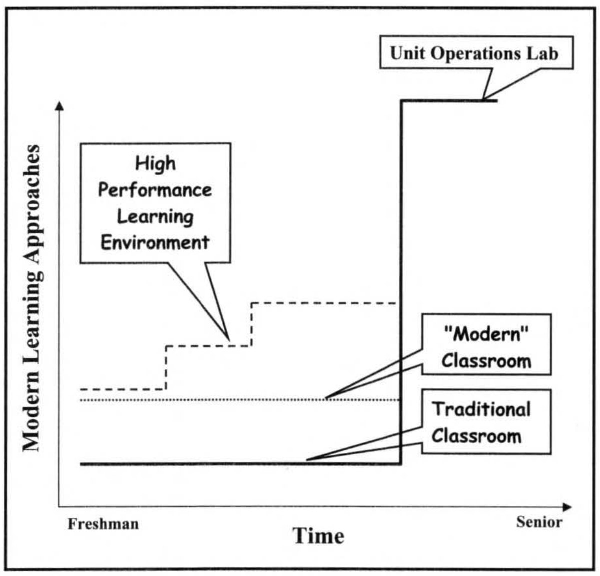

***Figure 1.*** *Learning timeline for ChE undergraduates.*

As a general guideline for the breakdown of the course grade, the experimental prototype must have substantial weight in the overall grades for students in the course.[10,16] Indeed, we based 25% of the course grade for the teams on their respective experimental prototypes. This 25% was split into two components: 10% for a written report on the project and 15% for a poster competition.

Students found the poster competition to be exciting. It served as a presentation and assessment forum, taking place in the central atrium of the college where all students, faculty, and staff could look and interact. The judges were external to the course, often from different departments or even from different universities. They were given a general set of guidelines, but the actual decision of using or modifying them was left to the panel.[16] As an alternative to the poster presentation, we have used a seminar presentation with faculty members (other than the instructor) as the assessors.

The final two-hour written assessment for the course, (weighted at 25% of the overall grade) covered *all the projects* in the course. This approach broadens students' practical knowledge of the course subject and reinforces their ability to learn and apply fundamentals. To help students become familiar with their peers' projects, teams periodically gave oral presentations to underscore pertinent physical principles, to communicate the progress, and to respond to questions. The instructor, as coach, could stimulate further discussion on aspects that may not be clear to everyone.[6,7] Often, these project sessions were scheduled during special recitation meetings. They also served as rehearsals for the final poster competition where the students had to convince the judges of their knowledge and understanding of basic concepts and their application to the experimental prototype.

While 50% of the overall grade was directly related to the projects, as explained above, the remaining 50% covered problem solving related to fundamentals, such as the four topics presented in Section A of Table 4. These topics prepared students to undertake projects listed in Section B of Table 4. Student learning was assessed through homework, midterm exams (typically three), and course folders. Pop quizzes and informal group activities in class proved useful in monitoring student progress and also led to the implementation of corrective measures, such as additional homework assignments, to address deficiencies.

The results of the assessment showed a dramatic increase in student ability to solve problems of high complexity, a level of student confidence not observed in previous courses, and an independent and active student engaged in the process of solving and/or implementing a task. In particular, students exposed to a Hi-PeLE showed a degree of creativity and readiness not found in those who had not been exposed to this learning environment; these characteristics were almost totally absent in students not trained in a Hi-PeLE when they were in the UOL activities. The reader interested in more details is referred to Sauer and Arce.[16-18]

## TRANSITIONING TO THE UOL

Since in Hi-PeLE the students work in teams and are exposed to experiments, they acquire a solid preparation for the unit operations laboratory (UOL) course. This benefit is illustrated in Figure 1, which compares the impact of three learning approaches in the curriculum from the freshman year until students reach the senior year of their chemical engineering major.

Students who follow the traditional classroom environment (see equation 2) experience few modern learning approaches during the freshman and sophomore years. Suddenly, in their junior or senior year when they enter the UOL, these students face a high step up to intensive teamwork, report writing and presentations, and the application of fundamentals to experiments. An improvement is observed at earlier stages when the modern techniques, listed in Table 2, are introduced into the classroom. The level, however, is bounded because of the limited team structure and lack of hands-on experimentation.

Finally, the Hi-PeLE exposes students to issues of teamwork, communication, experiments, and equipment while in the classroom course and, therefore, offers the best possibility for helpful preparation towards the UOL.

## FACULTY LEARNING AND COLLABORATION

For faculty involved in Hi-PeLE, the opportunities for professional development are superb. They are exposed to a variety of teaching techniques that will enrich their knowledge and help them in becoming a "modern" engineering instructor. The Hi-PeLE methodology also encourages a close, ongoing interaction of classroom instructors with the UOL instructor and hence helps build a common language among faculty.[20] These personal relationships bridge aspects related to the experimental component of the curriculum that too often are segregated from the classroom. The Hi-PeLE thus tends to stimulate faculty collaboration across the entire department. Since the faculty is familiar with the educational methodology of the UOL and because of Eq. (1), the interaction offers an economical, gradual way to encourage "traditional" classroom instructors to adopt modern learning approaches.

## CONCLUDING REMARKS

Hi-PeLE exposes students to an environment that works as a mini-version of real-life engineering. There are no lectures. Instead, students work together, program their activities, initiate industrial contacts, solve problems, and complete oral and written reports in order to design, develop, demonstrate, and document experimental prototypes. Thus, students acquire a sense of what chemical engineering is all about and the endless creative and practical possibilities that our profession offers.

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