

Problem-Based Learning and Interdisciplinary Instruction

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Abstract

This paper describes the development and implementation of a problem-based learning approach for interdisciplinary instruction in introductory courses for engineering technology majors. Required general education courses in mathematics, physics, and communication have been integrated with introductory engineering technology courses. This project was undertaken to improve the retention of students in engineering technology curricula and meet the challenges of producing engineering technicians for the 21st century.

The first step in creating an integrated curriculum was forming interdisciplinary faculty teams to identify and validate integrated competencies. Technical college faculty from all 16 South Carolina technical colleges participated in this validation process. As a next step, design teams comprised of interdisciplinary faculty and industry representatives developed the workplace scenarios or problems. SC Advanced Technological Education industry-based problems provide a mechanism for integrating subjects and an important new context for student learning. Industry focus groups were used to validate the technical accuracy and relevance of the scenarios' application to the workplace and work of technicians.

Interdisciplinary faculty teams now provide instruction and coach student teams as they learn how to use a problem-based learning process to construct knowledge needed to arrive at scenario solutions. The paper will not only present details of the development and implementation of this problem-based learning approach but also share lessons learned, student outcomes, and how this approach fits with the TAC-ABET Criteria.

I. Introduction

A strikingly significant ramification of the ongoing struggle to remain competitive in the world market is a dramatic shift in responsibilities and expectations of the American technical workforce. New technologies and workplace processes are requiring a move from the traditional manual industrial worker to the expanded role of an engineering technician, who works with his/her hands and applies theoretical knowledge. This redefined technician role in the manufacturing environment requires immediate changes be made in two-year college engineering technology programs.

The current educational model in many engineering technology programs consists of courses divided into isolated disciplines and taught in traditional semester or quarter terms. No

programmatic or faculty interaction occurs between general education and engineering technology "divisions." The invisible barriers between courses and disciplines is typically felt by students when taking required general education courses; the connections to their chosen area of focus in engineering technology is most often difficult for students to see. To improve the education and workplace readiness of technicians, artificial discipline and faculty barriers must be removed. In industry, technicians will be expected to operate in a more fluid, non-compartmentalized setting, integrating skills from many disciplines (mathematics, science, communications, and technology) to solve problems. An educational model that reflects the workplace by integrating these disciplines around an industrial-type problem can remove isolation between academic departments and better equip students to function successfully in the workplace.

Educational research provides guidelines for such a curriculum change. Gardner (1), in presenting his concepts of multiple intelligences and Felder (2), in comments on students' learning styles, show that students require instructional strategies that differ from the traditional lecture format. Brown and Brown (3) describe how the use of problem-based learning strategies effectively incorporate real-world problems, an interdisciplinary environment that models the workplace (especially teamwork), and desired pedagogical techniques such as active learning and collaborative learning.

In the South Carolina Technical College System, the identified goal was to reform engineering technician education in such a way as to increase the quality, quantity, and diversity of technical graduates to support economic development efforts. This engineering technology reform effort is being conducted through the SC Advanced Technological Education (SC ATE) Center of Excellence, which is funded by the National Science Foundation and the SC State Board for Technical and Comprehensive Education.

Studies of student retention (4) in the SC Technical College System have shown that the critical gatekeeper courses in engineering technology are not the technical courses but the entry-level mathematics and physics courses. Therefore, the first step was to improve student retention in first-year mathematics, physics, communications, and technology courses. To make first-year course material more relevant to technical students, curriculum changes must enable these courses to model the workplace. The focus on modeling the workplace led to a curriculum model that incorporates an interdisciplinary, problem-based approach to delivering course content.

The process to developing this curriculum model includes:

- Faculty preparation.
- Development of integrated curriculum and integrated curriculum competencies.
- Development of problem scenarios.
- Industry focus groups, pilot-testing process and national peer review.
- Faculty teaching teams, classrooms (scheduling and arrangement), and role of the instructors.
- Problem-based learning process.
- Lessons learned.

Finally, student outcomes and how the SC ATE approach may fit with new proposed accreditation criteria are discussed.

II. Faculty Preparation

Faculty members are constantly refining their courses to improve the student learning outcomes. Their refinements are the result of applying new and innovative instructional methods and may or may not encourage change among fellow faculty members. However, to successfully initiate systemic change among a number of colleges or a large segment of one college, it is vital to begin the reform process at the grassroots level, with a change among faculty. Systemic curriculum reform can only begin with a reform-minded faculty. (5)

To move toward the development of interdisciplinary, problem-based curriculum materials, it is necessary to first develop interdisciplinary faculty teams. In South Carolina, each college in the system was requested to select an interdisciplinary team (one faculty member from each of the four disciplines: mathematics, science, communications, and technology) to participate in a series of Chautauqua-type workshops. These workshops, given over the course of a year, introduced faculty to the concepts of curriculum integration, teaming, multiple intelligences, learning styles, problem-based learning, collaborative and active learning, and assessment. These workshops used the Chautauqua structure, with the teams testing an instructional strategy learned in one workshop before the next workshop. This process produced a cadre of reform-ready faculty to participate in the curriculum development and review process. Most colleges sent faculty volunteers to participate in interdisciplinary teams; however, several appointed faculty to participate. The teams formed of volunteers became productive teams much faster than the appointed faculty members.

Lesson Learned: Volunteers for change make the most effective faculty members to participate in a grassroots reform process. Even then, the change process is slow and must be nurtured and supported over time.

III. Curriculum Development

An interdisciplinary oversight team was formed to guide the curriculum development process. This team consisted of three project principal investigators (PIs) for SC ATE and one faculty member from each of the four disciplines. Faculty selections were made to statewide representation. Responsibilities were to

guide the curriculum development process, develop criteria and standards for the development teams, help in the identification of the development teams, facilitate the work of the development teams, and review the products of the teams to ensure consistency and continuity. The curriculum development model was

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|------|--|
| I. | Identification of integrated competencies. |
| II. | Creation of workplace problem scenarios. |
| III. | Development of instructional strategies. |
| IV. | Pilot testing of materials. |
| V. | Revision of curriculum materials. |

Table I Steps for Integrated Competencies

designed to draw on the expertise of as many of the trained faculty members as possible. All the development teams consisted of interdisciplinary faculty from colleges throughout the state, with no team having two faculty members from the same college. Development involved a five-step process (see chart).

Orderly integration of a large number of courses and disciplines requires a set of development criteria and framework. The oversight team determined the following criteria for the development of the integrated competencies.

- I. Integrated courses would replace the existing entry-level mathematics, physics, communication, and engineering technology courses (up to 30 credits).
- II. Exit competencies would prepare students to enter in to the engineering technology curriculum for the SC Technical College System.
- III. The curriculum framework would be built around physics, because physics has the least flexibility in the content development.
- IV. The sequence begins with electrical to be in sync with the electrical/electronic engineering technology programs.
- V. The team identified six major physics topics to develop: Electrical, Mechanical, Materials, Fluids, Thermal, and Optics.
- VI. Only two topic areas would be developed at a time.

Table II development criteria

The oversight team developed the following timetable for material development. (6)

SC ATE INTEGRATED CURRICULUM FOR ENGINEERING TECHNOLOGY

| | Spring '97/ Fall '97 <i>Spring '98</i> | Fall '98 <i>Spring '99</i> | Fall '99 <i>Spring '00</i> | Fall '00 <i>Spring '01</i> | Fall '01 <i>Spring '02</i> |
|--|---|---------------------------------|---------------------------------|--|-------------------------------|
| COMPETENCIES Mathematics Science Communication Technology | Electrical Mechanical <i>Thermal Fluids</i> | <i>Optics Materials</i> | | | |
| PROJECTS Scenarios Workshops | <i>Electrical Mechanical</i> | <i>Thermal Fluids</i> | <i>Optics Materials</i> | | |
| PILOT TESTING | | Electrical <i>Mechanical</i> | Thermal <i>Fluids</i> | Optics Materials | |
| REVISIONS | | Electrical | Mechanical <i>Thermal</i> | Fluids <i>Optics Materials</i> | |
| SOUTH CAROLINA IMPLEMENTATION | | | Electrical <i>Mechanical</i> | Thermal <i>Fluids</i> | Optics Materials |
| NATIONAL PEER REVIEW | | | Electrical Mechanical | Thermal Fluids Optics Materials | |
| WORKING PRODUCTS | | | Technology Gateway | | ET Core |
| <i>Grant Year</i> | 1-2 | 3 | 4 | 5 | 6 |

Table III Curriculum Development Timetable

Lesson Learned: The establishment of the oversight team with faculty representation from each discipline gave all faculty ownership and established a liaison and spokesperson for each discipline that helped with the faculty buy-in.

IV. Integrated Competencies

The development of the integrated competencies for each area was done over the course of a semester. Interdisciplinary faculty teams, selected from volunteers from technical colleges across the state, comprised the development teams. The engineering technology team members were drawn from departments related to the topic area being developed. Teams assembled for a two-day retreat to establish initial competencies, following the development plan below. Teams were

first lead through a brainstorming process by a facilitator. The development teams later edited the competencies via e-mail and teleconferences to produce a product that was finalized at a second retreat.

- I. Each team member was charged with reviewing the competencies presently taught in the entry courses for the topic area (communication, mathematics, physics or technology) and bringing that list to the first meeting.
- II. At the first meeting, the facilitator had team members present the competencies and a recorder listed each on a separate sheet of paper. There was no attempt to organize at this point.
- III. An affinity process was used to place the competencies into categories using the physics structure.
- IV. The affinity process produced a dialogue among physics, mathematics, and technology faculty that led to refining the integrated competencies.
- V. This process did not identify which of the communication competencies would best be learned or needed.
- VI. Faculty members then developed a set of competencies to be completed by the students by the end of these courses.

Table IV Problem-based Learning Scenario Development

The end product, an integrated listing and a discipline listing of competencies, was presented to a larger faculty group at an ATE retreat. The competencies were reviewed and suggested modifications made by discipline peer groups. The oversight team evaluated the suggested modifications, approved appropriate changes, and the competencies were published.

Lesson Learned: Writing communication competencies related to technical competencies was difficult. However, communications should be included in an integrated curriculum.

V. Problem Scenarios

For development of problem scenarios, new interdisciplinary teams were formed to develop workplace scenarios. These teams were comprised of faculty members and a manufacturing representative from an industry employing technicians in the topic (electrical, mechanical, etc.) area. The oversight team established the following criteria and a template for scenario development.

- I. Problem scenarios must be based on workplace/ manufacturing situations.
- II. The level of the problems must be consistent with the work that a technician would be expected to perform. Problems should relate to installation, modifications, troubleshooting or repair.
- III. Problems should be open-ended, with a loose structure and multiple solutions, if possible. Problems should require the students to seek information not given to assist in formulating a solution.
- IV. Problems may have constraints to limit the complexity for entry-level students. Most industrial problems are so complex that they would be impossible for first-year students to solve.
- V. Scenarios must cover the content for a given topic area. The problems provide the context for the learning. They establish a reason to learn facts, concepts, and procedures. They provide the vehicle relating the disciplines to “real-world” problems.
- VI. Problems should be able to be completed in two to three weeks.

Table V Problem-based Learning Scenario Criteria

Faculty teams were given the integrated competencies and the topic area as a guide, but were not given a fixed sequence. Faculty members first brainstormed a series of scenario ideas that would possibly cover the topic area. These were selected to meet the physics/technology sequencing typical in a beginning course. Then faculty began the task of developing a scenario in-depth.

During the development of the problem scenario, it was possible to identify the communications competencies to be completed.

- I. Background material was needed to tie the physics and technical concepts to the workplace application.
- II. Scenario statements were to include the workplace situation and the criteria for problem resolution.
- III. Projects should include identification of the competencies to be taught.
- IV. Projects should include strategies to be used in the students learning process.
- V. Workshops or lessons to be presented to the students to help develop solutions to the problem were to be a part of each project/problem scenario.
- VI. Content structure for the four disciplines would show the integrated sequencing of content.
- VII. Assessment techniques would be identified.

Table VI Project Material Development

Once the scenario draft was completed, the integrated competencies required by the scenario were identified. On completion of the scenarios for an area, the competency list was reviewed and scenarios refined to ensure that all competencies were included.

| Number of Scenarios Developed by Topic Area | | |
|---|----------------|---------------|
| Electrical - 5 | Mechanical - 5 | Materials - 2 |
| Thermal - 1 | Fluids - 1 | Optics - 2 |

Table VII Projects

The diagram below shows the interrelationship of the PBL Scenario and the four disciplines.

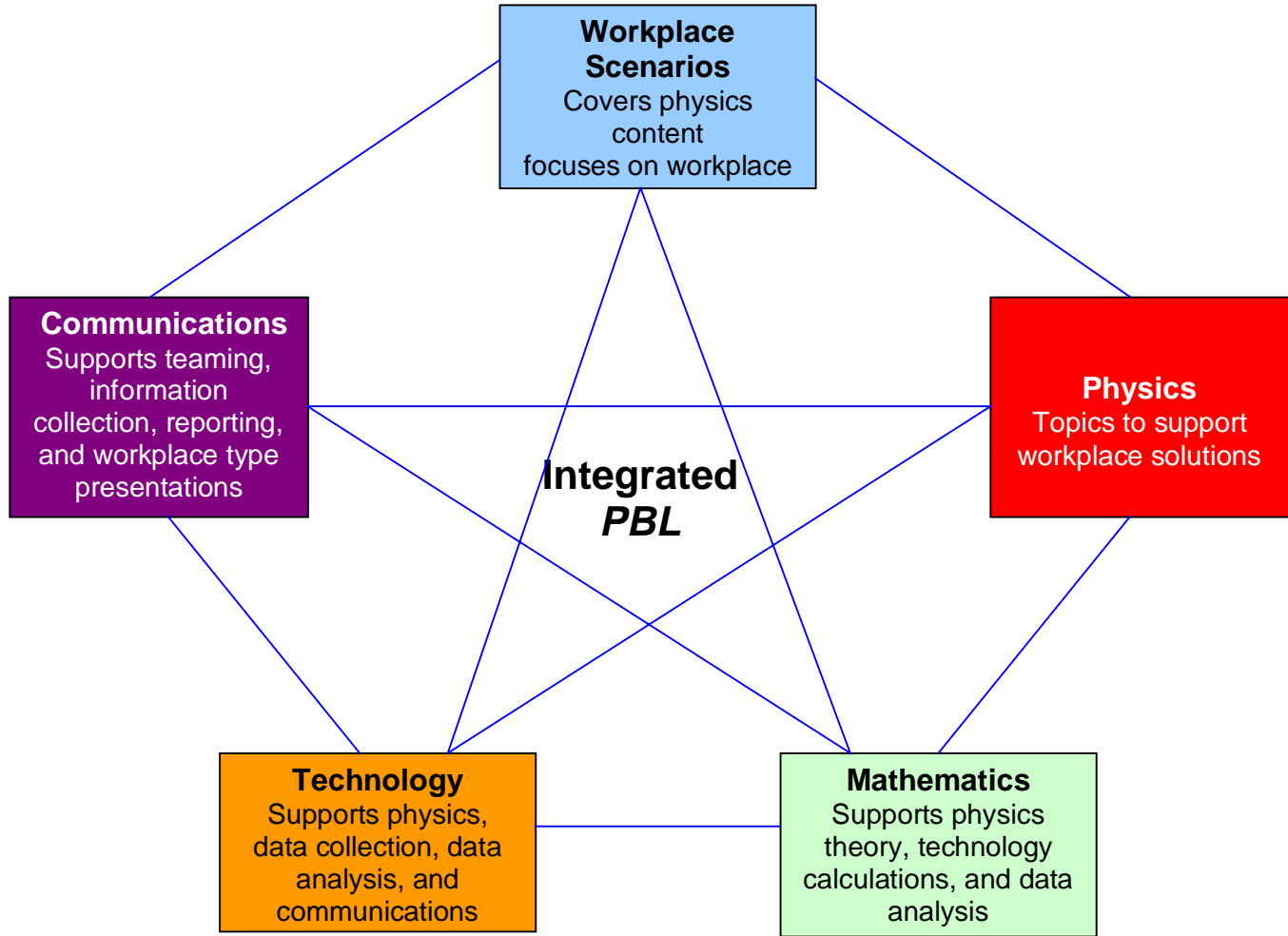


Figure 1 Integrated Material and Problem Scenario Relationship

Lesson Learned: The inclusion of an industrial representative in the scenario development team brought a balance and a more complete industrial perspective to the development team.

VI. Industry Focus Groups and National Peer Review

An important part of the scenario development was validating the applicability of the scenario to the technician's job. Industrial focus groups were used to validate the scenarios. Industrial representatives from local industries were invited to a session to review the competencies and scenarios. The representatives were first presented an overview of the problem-based learning (PBL) process and the general goals of the materials. The course material to be reviewed were for entry-level courses, not exit courses. Industry representatives needed to understand that students would have limited abilities in some content areas.

Industry focus groups (ranging in size from four to eight) were given two scenarios to review. They were asked to determine the appropriateness of the problem scenarios, and to make a determination of the level of the scenario. Suggestions for improvements were requested to make the scenarios more appropriate to possible industrial situations. Focus groups were asked to rate and comment on the scenarios according to the following criteria.

- Significance of the problem in an industrial setting.
- Appropriateness/clarity of the problem scenario.
- Enhancements to the problem scenario.
- Suggested alternative to the problem scenario.
- Suggested alternative to the presentation.

Focus groups also were asked to evaluate the competencies. They evaluated them on a five-point scale (see chart).

The input from focus groups provided a better understanding of industry expectations of technicians. For example, a representative commented that a particular task would be solved by an engineer rather than a technician; however, the concept involved was something a technician was still expected to understand. This type of input was valuable in suggesting student performance expectations.

| |
|--|
| <ol style="list-style-type: none"> 1. Not needed. 2. Nice to know. 3. Basic skill for entry level. 4. Apply without supervision. 5. Instruct others to use. |
| <p>Table VIII Focus Group Rating Scale</p> |

A second validation was provided through a national peer review of the materials. This review was conducted by a nationally recognized interdisciplinary group of educators representing each of the disciplines. This second level added another level of evaluation.

Lesson Learned: Material review and evaluation need input from multiple sources with different perspectives. Industry input, focused on workplace skills, must be balanced by faculty input to provide a broad-based educational foundation.

VII. Faculty Teaching Teams

Faculty pilot teaching teams became part of the development process. After the materials were pilot-tested, teaching teams reviewed the materials for completeness and ease of teaching. Also, teaching teams reviewed teaching strategies and incorporated them into a more detailed listing of strategies to be included with the instructional materials.

The instruction process is team-led and team-learned. No longer can faculty members treat their content area as independent of other disciplines. It is critical that each teaching team plan and coordinate its activities. In the initial phases of the course, the team must develop a scope and sequence for the delivery of material. There should be a team meeting each week to assess student progress and to determine the work for the next week. Even with these team meetings, it is important that the faculty keep in daily contact through informal discussion, e-mail, or telephone. One successful technique is to keep a logbook of activities in the classroom and

record at the end of a session the status of that class. This logbook is kept in the classroom, and all instructors have access to it.

In problem-based learning, there is a change in the role of the instructor. The classroom is no longer teacher centered, but student centered. The instructor functions as a guide or coach for student learning activities. It is through guiding, probing, and supporting students' activities, not through traditional lectures or providing easy questions, that information is delivered to the students. The degree to which the activities are student-directed versus teacher-directed, however, will depend on how far along the students are in applying the PBL process. In the first classes, the instructor must provide more instructor-directed teaching until the students have obtained the maturity and confidence necessary to take on more responsibility for their own learning.

Lesson Learned: A well developed teaching team is the key to successful presentation of the integrated materials.

VIII. Presentation

The process of presentation of the materials is critical to the instructional methods. In the presentation of the scenario, there are several steps that aid student understanding.

Prepare the Student: The student is given an activity that leads to an understanding of the problem. The activity may be used to help set the industrial context of the scenario. It is used to give the students background information that is not directly related to the scenario.

Present the Problem: This places the student in the industrial setting as much as possible. The key is to give the student the scenario in a way that is similar to how it would be given to a technician. The presentation may be in the form of role playing, a video that presents the problem, a memo, etc. The students also are given support materials such as diagram, CAD drawings, and data sheets at this time.

Analyze the Problem: The initial analysis of the problem is by developing a "Know, Need-to-Know" chart. Students use the chart shown in the figure below to begin analysis of the problem. The key to this part of the process is the coaching by the instructor. With good coaching and guided discussion, students can be guided to list in the "Need-to-Know" column the workshops that will be covered in the study.

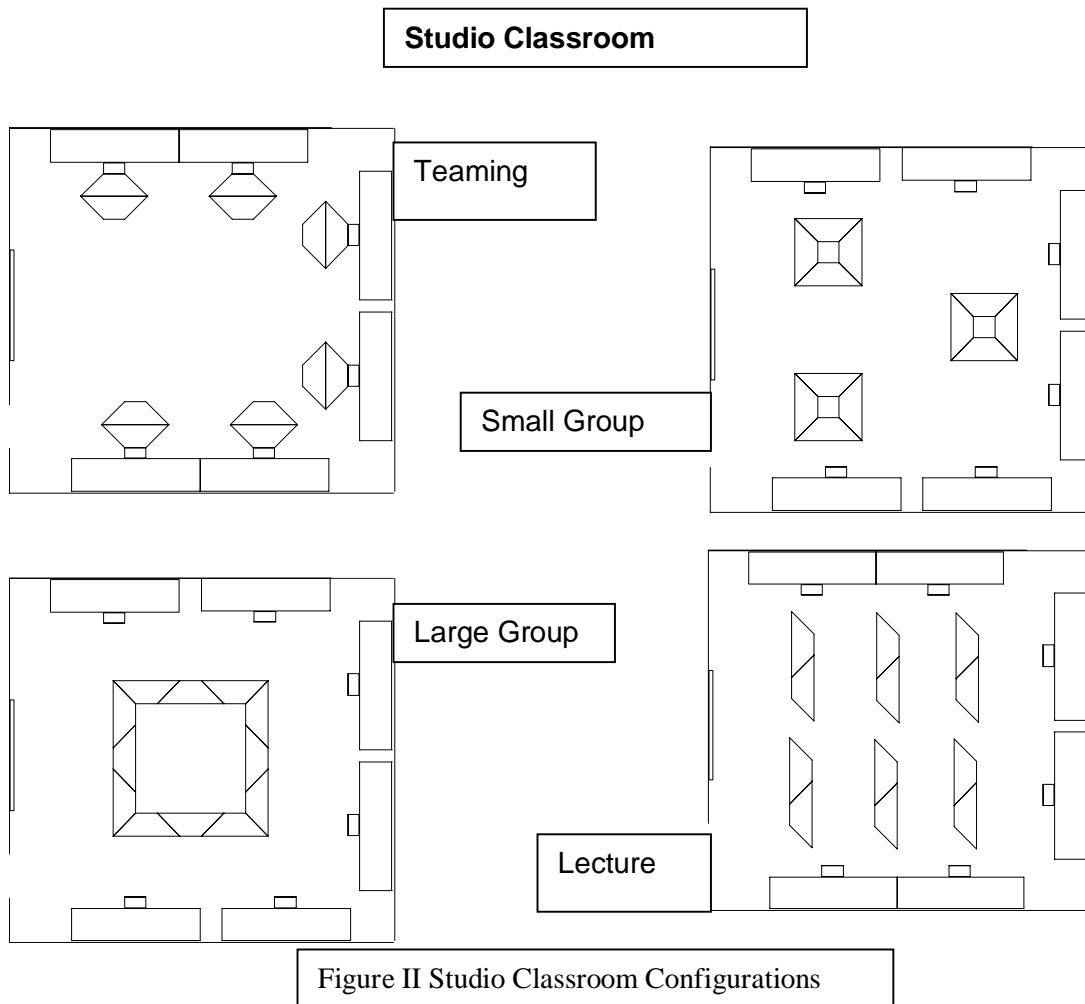
Workshops: Students do not have sufficient knowledge to solve the scenario and must be given workshops activities that aid in the development of the concept for mathematics, physics, technology, and communication. These workshops are designed to give the students a global understanding of the concepts related to the problem

Analysis: The student teams use the information from the workshops to analyze the problem. They must decide what information from the workshops is relevant to the problem and how to apply it.

Lesson Learned: The presentation of the problem scenario and coaching by the faculty in the analysis of the problem is critical to the students' understanding of the PBL process.

IX. Classrooms: Scheduling and Arrangement

In contrast to traditional scheduling, ATE engineering technology classes are scheduled in blocks of time to permit student teams to remain on the problem task for extended periods of time. Typical blocks are two and three hours. Also, room scheduling is important. All classes are held in the same room. This gives continuity to the students, and gives them "ownership" of the room. Room arrangement is critical. The room should facilitate teaming and an active learning environment. The diagram below shows the arrangement of a studio classroom that has laboratory workstations around the perimeter of the room and allows for arrangement of tables to facilitate teaming, small groups, large groups, and lecture activities.



Process for Integration, Problem Development, and Implementation

- Identify discipline areas to integrate
- Select one discipline to provide structure or content flow
- Select interdisciplinary team members from each discipline
- Develop entry level criteria
- Set exit competencies
- Validate with interdisciplinary faculty

**Integrated
Competencies**

- Use advisory committees to identify local industrial situations
- Visit local companies to look for situations
- Look for cutting edge technical needs on the national scene that would be of interest to the students
- Use troubleshooting case studies

**Define the
Scenario**

- Decide on the student's role and the situation
- Establish the project goal or outcome
- Prepare a scenario statement
- Develop scenario documents
- Determine the framework competencies
- Develop performance assessment

**Develop the
PBL Project**

- Identify critical teaching and learning events
- Identify the embedded workshops
- Develop embedded assessment
- Establish learning structure

**Teaching &
Learning
Workshops**

- Prepare the students
- Meet the problem
- Develop KNK (Know-Need to Know) chart/concept map
- Develop problem statement
- Deliver workshops
- Consider solutions
- Fit the solutions

**Coach T & L
Workshops**

- Assess development of KNK charts
- Assess problem statement
- Assess development of concept maps
- Deliver appropriate instructional workshops and activities

**Embedded
Assessment**

Adapted from IMSA Model

X. Student Outcomes

The number of students enrolling in ATE engineering technology classes has increased 51 percent (year 2000 enrollment data is based on faculty reported data as of 10/10/00). The number of female students is up 15 percent and number of African-American students is up 29 percent. Retention rates have been 76-100 percent in each term since pilot implementation began two years ago. The graduation rate of the first "pilot class" students to have been engaged in the SC ATE engineering technology first-year program is 50 percent, with additional students expected to graduate within the academic year. When the ATE effort was started, the graduation rate for engineering technology was about 10 percent. The number of SC ATE faculty (full time and adjunct) continues to grow, with 128 faculty members involved (as of 9/13/00). Industry interest in and support for the program also continues to broaden, as reflected through the growth of a SC ATE Scholars initiative. Through the ATE Scholars initiative, industries help identify and recruit engineering technology students, and offer competitive scholarships and relevant, paid work experience.

XI. SC ATE Approach and Proposed TAC of ABET Criteria

The SC ATE curriculum appears to be consistent with the new general criteria for engineering technology programs, proposed by the Technology Accreditation Commission (TAC) of the Accreditation Board for Engineering and Technology (ABET). Some aspects of the criteria reflect instructional approaches that mirror approaches integral to the ATE curriculum. For example, TAC of ABET 2000 Criterion 1, on preparation of students and graduates, proposes:

- "Apply creativity in the design of systems, components or process appropriate to program objectives." The open-ended ATE problem scenarios encourage creative solutions, with not expectation of only one correct answer.
- "Function effectively on teams." SC ATE students work in teams throughout their ATE experience.
- "Identify, analyze and solve technical problems." The ATE integrated curriculum revolves around industry-validated technical problems.
- "Communicate effectively." Communications is a vital component of the ATE integrated curriculum, whether students are communicating as a part of a team or formally presenting problem scenario solutions.
- "Are aware of and respect diversity." ATE faculty members have participated in extensive faculty development on appropriate teaching methods to support the learning needs of a diverse population of learners. This sensitivity to and respect for diversity is modeled in ATE classrooms.

XII. Conclusion

Reforming the curriculum approach to engineering technician education can dramatically impact student learning and retention. The SC ATE approach provides one effective model of reform. Beginning with reform-ready faculty, administrative support, and the involvement of industry, South Carolina has developed an integrated, problem-based first-year curriculum that models the workplace. This approach is proving successful in increasing the quality, quantity, and diversity of engineering technology graduates.

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