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ABSTRACT

In the face of increasing specialization and employer demand for higher skill levels, a new paradigm for engineering education redirects the primary focus from the engineering knowledge base (content) to the development of thinking and problem solving processes. The principles of this "Process Education in Engineering" paradigm are: (1) faculty must take responsibility for the quality and performance of student learning, thinking, and problem solving; (2) every student can improve his/her ability to "learn how to learn better"; (3) a significant portion of class time should be allocated to learning and problem solving skills where faculty and other students can assess and provide feedback; (4) active learning approaches provides an excellent way to leverage faculty resources and improve student self-confidence in thinking and learning skills; and (5) engineering courses, through content mastery, offer many opportunities for developing life-long skills such as reading, listening, critical thinking, problem definition, modeling, leadership and technical communication skills. Process Education is the philosophy that learning, thinking, problem solving, communication, teamwork, and assessment are processes to be developed by students as they master the content of the discipline. Cooperative learning, discovery learning, technology, journal writing, and assessment are tools and techniques that support Process Education. Innovative freshman and sophomore courses in engineering and engineering technology have adopted this new paradigm and realized its benefits. (Contains 12 references.) (JB)

TRANSFORMING ENGINEERING EDUCATION FROM A PRODUCT TO A PROCESS

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This paper introduces a new paradigm for engineering education that redirects the primary focus from the engineering knowledge base (content) to the development of thinking and problem solving processes. The benefits of adopting this new paradigm have been realized in innovative freshman and sophomore courses in engineering and engineering technology.

Introduction

Over the last one hundred years engineering education has become more and more specialized. During the first half of this century major departments were formed -- mechanical, electrical, chemical, agricultural, and civil engineering. During the last half of this century each of the major disciplines have become divided into a multitude of sub-disciplines. Now even the sub-disciplines are advancing so fast that they cannot be comprehensively presented in a four year curriculum. Employers are demanding higher skill levels in their current and prospective employees because with lean corporate staffing levels and ordinary skill levels, the latest technology cannot be adopted quickly enough to maximize competitive advantage [1,2,3].

The fundamental issue facing engineering educators is: should we concentrate our efforts on continually modifying present courses and methods to incorporate new content, concentrate our efforts on providing skills employers want, or reinvent engineering education by considering alternative paradigms? Considering data from various studies as well as ABET guidelines, the paradigm proposed here is based on the principles outlined in Figure 1 [3,4].

1) Faculty must take responsibility for the quality and performance of student learning, thinking, and problem solving.

2) Every student can improve their ability to "learn how to learn better" regardless of their level.

3) Learning and problem solving skills are best developed by allocating a significant portion of class time to these activities, where faculty and other students can assess and provide feedback.

4) Active learning provides an excellent way to leverage faculty resources and to improve student self-confidence in thinking and learning skills.

5) Engineering courses, through content mastery, offer many opportunities for developing life-long learning skills such as reading, listening, critical thinking, problem definition, modeling, leadership, and technical communication.

Figure 1 Principles of Process Education in Engineering

Paradigm of Process Education

Process Education is the philosophy that learning, thinking, problem solving, communication, teamwork, and assessment are processes to be developed (and continually improved) by students as they master the content of a discipline area [4]. Process Education is lively, timely, and systematic. It is concerned equally with content (discipline specific knowledge) and skill development. Currently in engineering, much of the skill development that we expect our students to undergo occurs during the design process.

In Process Education, the main goal is to empower students to become life-long learners, both capable and eager to learn new concepts on their own [4,5]. Educators become facilitators of the learning process, assessing students' performance in real time to help their growth in the use of these processes. The following tools and techniques support Process Education: cooperative learning, discovery learning, technology, journal writing, and assessment.

Cooperative Learning

Cooperative learning provides an excellent way to leverage faculty resources and to improve student self-confidence in thinking skills. Cooperative learning is a structured process in which a team masters the learning objectives for a defined activity. Cooperative learning teams have been shown to significantly outperform individuals in mastering content within a time constraint based upon set performance criteria [6,7]. Furthermore, students benefit from and demonstrate significant improvement in process skills through cooperative learning. The additional process skills that are used in the cooperative learning environment include: (1) communication skills such as conversation, articulation of concepts, and presentation of results; (2) teamwork skills such as leadership, decision making, conflict resolution and collaboration, and; (3) assessment, either in real time as they work through problems together or afterward in reflection, as they assess each other's team skills, thinking, and problem solving processes. By building on each other's strength and ideas, students can learn faster and better with cooperative learning [7].

Discovery Learning

A critical and unique aspect of Process Education is that students rather than faculty access appropriate information, process this information, discover the appropriate concepts, think critically about these concepts, and apply this to problem solving situations. The discovery process can vary from a carefully guided activity as in many lab handouts to a very open process as in a design project. In guided discovery, the teacher provides learning resources such as mathematical models or reference data along with a set of carefully designed questions. Key components of discovery learning, include learning objectives and outcome criteria, models and tools, and context dependent exercises. In addition problem solving activities help students process the information resources and construct conceptual knowledge themselves.

Discovery based learning and applied critical thinking are linked [4,6,8]. The key is that students are allowed to be the active agent in the learning process. One of the primary admonitions given students is to "Try It!". While it is tempting to "help" students by providing eloquent and informative responses to questions, this interrupts the discovery process. The most constructive intervention the teacher can make is to ask additional critical thinking questions. Retention and satisfaction are far greater if the solution is discovered by the student rather than provided by the faculty [4,8].

Problem Solving

Students need to solve problems to develop skills in applying knowledge. Problems may start with straightforward application of the concepts discovered. Next, concepts can be integrated with other concepts, generalized, and transferred to new situations. Higher level thinking can often be generated in later problems by omitting information, requiring assumptions, or including superfluous but seemingly relevant information. Problems with multiple parts promote critical thought since students must identify and separate the parts, organize the information relevant to each part and decide what needs to be done. Solving problems validates the students' understanding of concepts and gives relevance and value to the knowledge constructed [8].

Technology

Computers are an important tool to facilitate student learning and skill development [8,9,10]. In general, technology can play a useful role in enhancing cooperative learning, discovery learning, and problem solving by:

- serving as a focal point for group discussion;
- providing an interactive environment to explore and test assumptions;
- presenting problem solving opportunities;
- promoting visualization of abstract concepts;
- encouraging self-assessment based on immediate visual feedback;
- maintaining a record of students' thought processes.

Journal Writing

Through group and individual journal writing, learners are given opportunity and encouragement to reflect upon what they have learned, to articulate and generalize concepts, and to learn from problems or difficulties they have encountered along the way. Journal writing also provides a convenient method to develop critical thinking and communication skills [10]. The key to developing writing skills is regular practice as well as regular feedback. Well-constructed journal writing exercises help students to know themselves and to cultivate professional values.

Assessment

Self-assessment is an important part of each activity and is essential if the student is to become empowered as a self-learner. We say that the difference between "thinking you know" and "knowing you know" determines whether or not the student can be considered a self directed learner [5,10]. To encourage self-assessment, the facilitator needs to establish an environment where self-assessment is safe, achievable, and valued.

Throughout the classroom activities many skills are used, developed, and explored. In order to teach process skills, you must be able to assess in real time [4]. The average engineering instructor is quite capable of assessing the mastery of information and conceptual understanding but may need to improve his/her ability to assess process skills such as communication, teamwork, thinking and self-management skills [3].

Curriculum Development for Process Education

The recommended steps for developing activity sheets for Process Education are based on the Learning Process Methodology described in Figure 2 [11].

Step 1 -- Why: Justify why everyone is going to invest time and effort in learning the material. Learning is most efficient when there are identified objectives and relevance.

Step 2 -- Orientation: Provide an overview of the knowledge area you are going to explore by constructing a bridge to areas covered previously and by showing the direction the process is heading. Developing an ability to distinguish the forest from the trees keeps you from wasting time.

Step 3 -- Prerequisites: Give students the opportunity to see they have the necessary background to be successful in learning the new concepts. The prerequisite may, for example, consist of comprehension of a background reading assignment, familiarity with an analysis technique, or understanding a piece of equipment. Taking responsibility, by becoming prepared for a new learning experience, increases success and self-esteem.

Step 4 -- Vocabulary: Write a brief description of each key concept and vocabulary term. Doing this will increase comfort and effectiveness during the learning activity.

Step 5 -- Learning Objectives: Define your set of learning objectives. You should have overall learning objectives with specific learning objectives for each activity. Identifying objectives increases productivity by focusing you on the most important learning issues.

Step 6 -- Criteria: Establish criteria to measure quality of performance in meeting learning objectives. These criteria will guide the learners' performance in the most important growth areas.

Step 7 -- Information Resources: Build an effective information base for constructing knowledge. This might include textbooks, previous lecture notes, libraries, Internet, and other sources.

Step 8 -- Plan: Outline a scheme to meet the established criteria using the information resources. A plan should consist of steps that can be used to accomplished the activity within the time available.

Step 9 -- Concept Models: Provide one or more models that help in understanding and identifying relationships among information and the connection between abstract theory and application. Examples of models include diagrams, graphs, computer simulations, mathematical models, physical models, analogies, and first hand experiences.

Step 10 -- Critical Thinking Questions: Ask questions to help the learner construct knowledge from the information resources and models. By providing questions to guide students through an exercise we can foster thought about the important issues, exceptions to the general rule, boundary conditions, logical extensions to the concept and opposing concepts. Questions may be divergent, convergent, or directed. Divergent questions make students choose their approach from a number of possibilities. Convergent questions help students converge on a particular idea. Directed questions tend to have a single answer and help if students become frustrated.

Step 11 -- Skill Exercises: Practice applying the new concept in new situations. The ability to transfer and generalize concepts is important to moving to higher levels of thinking and learning.

Step 12 -- Self Assessment: Encourage students to reflect on what has been learned. Reflection is useful in building knowledge out of content. It is important for the student to be able to distinguish between "thinking you know" and "knowing you know". A learning assessment journal provides opportunity to document performance, and supplies feedback that will improve future performance.

Step 13 -- Problem Solving: Synthesize the individual concepts learned through problem solving projects. A problem solving methodology may be given to the student as a guide to the more complex situations requiring a problem solving strategy.

Figure 2 Learning Process Methodology

Implementation of Process Education

A class based on the Process Education paradigm is very different from a traditional class. A student (or faculty member) who expects and is comfortable with lectures and content based examinations can find the process class bewildering at first [4]. One is asked to work in teams, each member with a specific role, to complete tasks while the instructor wanders around asking questions rather than answering them. The student is asked to keep a learning journal, reflecting regularly on the learning process itself, recording questions or insights that come up in real time as well as after the task is complete [10,11].

Multiple groups of four students are commonly used to increase the effectiveness of cooperative learning and to implement the Learning Process methodology [6]. Each student in a group is responsible for a role such as captain, recorder, technology specialist, or reflector. All roles are critical, however; the role of reflector is least understood. The reflector's job is to give a frequent report self assessing the team's performance. If groups are smaller than four members, individuals may be assigned multiple roles. If groups are larger or if the exercise warrants, additional responsibilities such as planner, negotiator, spokesperson, modeler, optimist, pessimist, and so on may be assigned.

To facilitate Process Education, the instructor may assume responsibilities in several areas [4,10]. As a *leader/moderator*, the instructor develops and explains the lesson, defines the objectives, criteria for success, expected behaviors, and establishes organization (rewards, group structure, room structure, time structure). The instructor also provides closure to the lesson by asking group members to report answers, summarize major points, and to explain the strategies, actions, and results of the group. As a *monitor/assessor*, the instructor circulates through the class to monitor and assess individual team performance and to acquire information on student understanding and difficulties. As *coach/mentor* the instructor steps in by asking timely critical thinking questions to improve team performance or to guide the group through difficulties.

Classroom Examples

The second author has taught a pre-engineering course using Process Education at the University of Idaho, Moscow, over the past five years. The course involves active learning activities such as collaborative reading, Internet discussion groups, one minute papers, computer exercises, oral reflector reports, problem solving contests, design projects, and peer assessment. The course materials are based on the Learning Process methodology [8,11,12]. The students are encouraged to focus on asking relevant critical thinking questions, learning faster, learning better and practicing group problem solving skills. Alternatively, the faculty focus is to let students "Try It", to ask questions rather than give answers, and to motivate students with interesting and challenging questions.

Typically 40 students participate in the course each semester. Students work in groups of 2-5 on in-class exercises and weekly homework assignments. Each group submits one work product and all participants receive the same grade. Homework is weighted 30%, class participation 10%, two individualized midterm exams 30% and a final design project 30% of the grade. In course evaluations, all students agreed with the statement that concepts and problem solving methods learned in the course could readily be applied to other courses. Course evaluation averages were high. Examples of student comments include:

> "At first I didn't like the way the instructor wouldn't answer a question. Instead he would ask you another question right back. However in the end I found that way of helping to be most effective in making me think."
>
> "You learn more in courses where you take part in class."
>
> "I was surprised how well students worked together. This made the course more interesting and more fun."

The first author has been teaching an introductory computer applications course based on the Learning Process Methodology in the mechanical engineering technology program at Purdue University

Calumet, Hammond, Indiana. Students work in groups of four with assigned roles. The course involves active learning activities such as one minute papers, computer exercises, oral reflector reports, design projects, and peer assessment.

The class meets in a computer laboratory four hours per week. This is in-line with the lab oriented engineering technology approach that the majority of courses have an accompanying laboratory. There has been a noticeable improvement in student attitude and performance since Process Education was implemented. Student comments are positive and student evaluations high. A new Process Education computer lab has been outfitted this year at Purdue Calumet to support various engineering technology classes as well as an introductory foundations course.

Conclusions

Closure in Process Education requires a reflector's report. This report gives a team strength, an area for team improvement and an insight about the learning process. This format for conclusion is also useful here. The strengths of Process Education for engineering include:

- Increased student and faculty satisfaction with classroom activities;
- Increased student performance in many lifelong learning skills;
- Increased student mastery and ownership of engineering knowledge;
- Greater self esteem and motivation to complete additional course work.

Areas for improvement are:

- Broader participation in faculty workshops and teaching institutes that focus on Process Education;
- Greater selection of instructional materials that support Process Education at all levels of the curriculum;
- More student exposure to Process Education by instituting a foundations course for all freshmen in each discipline.

Finally, the authors would like to share three insights about process education. First, Process Education has immediate applicability to laboratory and design components of existing engineering courses. These already share some characteristics with the Process Education paradigm. Second, all lecture courses can be modified to include process education. Third, opportunities for growth in facilitating Process Education are unlimited, however this growth can be accelerated through the creation of *teaching/learning* groups which share successes and address challenges.

References

1. The Secretary's Commission on Achieving Necessary Skills (SCANS), US Department of Labor, "What Work Requires of Schools: A SCANS Report for America 2000," June, 1991.

2. Wingspread Group on Higher Education, "An American Imperative: Higher Expectations for Higher Education," 1993, The Johnson Foundation, Inc., Racine, WI.

3. Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education (ASEE), "Engineering Education for a Changing World," October, 1993, ASEE.

4. Duncan-Hewitt, Wendy and Daniel Apple, "A Primer for Process Education," 1994, Pacific Crest Software, Corvallis, OR.

5. Arah, Beverly T. and Daniel K. Apple, "Everyone Can Learn to Learn," 1993, NAFEO Conference, Washington, DC.

6. Duncan-Hewitt, Wendy and Dan Apple, *A Handbook on Cooperative Learning,* 1994, Pacific Crest Software.

7. Johnson, David W., Roger Johnson, and Karl Smith, *Active Learning: Cooperation in the College Classroom*, 1991, Interaction Book Company, Edina, MN.

8. Apple, Daniel K., Steven W. Beyerlein, and Mark A. Schlesinger, *Learning Through Problem Solving,* 1992, Pacific Crest Software.

9. Beyerlein, Steven and Paul Dawson, "Developing Pre-Engineering Problem Solving Skills Through the Use of Computer Technology," *1992 ASEE Annual Conference Proceedings*, pp. 1062-1065.

10. Hanson, David M. and Daniel K. Apple, "Process - The Missing Element," working paper submitted to the Journal of Chemical Education, 1995.

11. Apple, Daniel K., Marie Baehr, Grady Batchelor, Steven Beyerlein, Sarah Carroll, Robbi Demetrio, Karl Krumsieg, Eric Wignall, Editors, *Foundations of Learning,* 1995, Pacific Crest Software, Corvallis, OR.

12. Beyerlein, Steven, Martha Ford and Daniel Apple, "Using a Learning Process Model to Enhance Learning with Technology," 1993 *Frontiers in Education Conference Proceedings,* pp. 456-460.