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# Learning to Learn—Concepts in a First Power Engineering Course

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**Abstract**—Three well-known and widely accepted concepts in educational psychology are revisited. These are “inventory of learning styles,” “taxonomy of educational objectives,” and “metacognition.” Relationships among these concepts are highlighted. Often, a student can develop his (or her) own learning style by the process of metacognition. Ideas are borrowed from these concepts for use in a first-level power systems course. It is beyond a doubt that both cognitive and metacognitive skills are necessary for students to succeed in any course. While a semester-long power systems course leaves little time for critical thinking and passive reflection for students, certain activities may very well serve for some of these learning processes.

**Index Terms**—Bloom’s taxonomy, educational objectives, inventory of learning styles, metacognition.

## I. INTRODUCTION

**P**OWER systems design is a first course in power taught either as a required or an elective course to undergraduates in electrical engineering. It lays the foundation for power engineering studies. In most universities, this course is oriented toward balanced three-phase analysis. Much of the subject matter of this course can be found in the first ten chapters of the well-known textbook by Grainger and Stevenson [1]. Many other excellent textbooks are also available. Prerequisites are normally ac circuit analysis background, phasor algebra, and some three-phase power calculations—concepts that are covered in a second circuits or networks course. Thus, a majority of the students who enroll in this class will likely know resistance from reactance, yet will not be comfortable with conductance and susceptance concepts. (Ironically, admittances and susceptances abound in power system studies). This is usually the first indication that students do not look at a concept from a different angle than what they see in textbooks. Eventually, when advanced concepts such as synchronous machine models based on electromagnetic theory are introduced to the same students, they often find it quite overwhelming. Many students lack the ability of creative application of concepts and strategies that are taught in preceding classes to solve a problem at hand.

Some commonly observed hurdles that students face initially in the first “power” course are:

- current calculations in a three-phase load given voltage and power;
- using proper per-phase equivalent diagrams in three-phase systems to find voltage at source given voltage and current at the load;

- mass confusion between the use of line-to-line and line-to-neutral voltages—the so-called curse of the “root 3”;
- using complex representation for phasor voltage and/or phasor current—systems are ac rather than dc;
- transferring quantities in wye-delta transformers;
- lack of confidence in the use of per unit analysis.

Continued failure to resolve such issues leads to loss of motivation. Piling up additional complex concepts of power system analysis on these students only helps to weaken the learning process. In order to overcome such adversities, many instructors advocate the use of attractive slide presentations, in-class demonstrations, use of animation graphics, web-enhanced learning, and so forth. While these tools are all useful and have their own merits, they lack one important ingredient, and that is the fact that the instructor creates these solutions and not the student.

Surveys in the U.S. have shown that a significant number of engineering students—in some cases as high as 50%—do not finish their college degrees for various reasons [2]. Further complicating this situation, at least in the U.S., is that power engineering is generally failing to attract the brightest young minds. False perception of this field as an outdated engineering discipline is only part of the problem. A first course in this field is a difficult subject to teach because of the confluence of the core disciplines of circuits theory, electromagnetics, electromechanics, and sometimes power electronics. This field is difficult to learn because power networks exhibit unusual behavior and are therefore difficult to analyze. Students go from straightforward linear circuit relationships in their first circuits or networks class to highly nonlinear relationships in power networks. It could be argued that the power systems class may be the only course in the undergraduate electrical engineering curriculum which teaches nonlinear concepts. Aside from the complexity of the subject, teaching and learning preferences also have a direct impact on student motivation. And without motivation, higher student achievement is unlikely.

An attitude toward learning is created when a student possesses curiosity, motivation, and a drive to learn more. Teachers can promote awareness of the cognitive and metacognitive aspects of thinking and learning by engaging students in activities which require reflection. There is, of course, no known solution technique that is automatically guaranteed to imbue these virtues into a student’s mind. Any solution that an instructor can dream up faces the challenging task of dealing with the different learning styles of students. A student must learn to find the deficiencies in learning and make a conscious effort at getting better at learning. Thus, the concept of “learning to learn” is gaining momentum in the engineering community.

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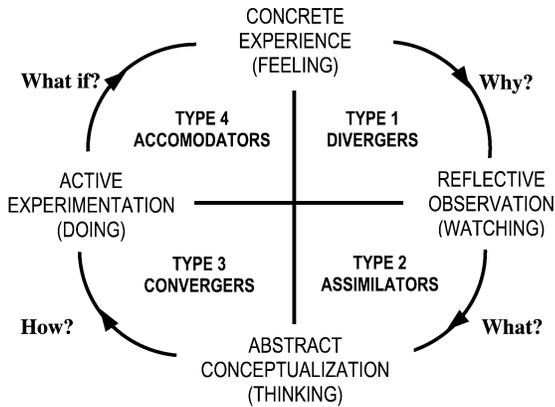


Fig. 1. Kolb's cycle of learning styles.

Before discussing the “learning to learn” concepts, we discuss the related concepts of “learning styles inventory” and “Bloom’s taxonomy of educational objectives.” Some of these ideas can lead to a successful foundation from which to build upon.

## II. LEARNING STYLES

Individuals perceive and process information in different manners. Educational psychologists believe that students tend to learn more effectively if they are taught in their preferred styles. The learning styles theory is based on research that is rooted on the fact that heredity and upbringing influences different individuals to perceive and process information differently.

Kolb [3] suggests that learning styles can be described by the diagram shown in Fig. 1. This diagram depicts four specific types of learners: divergers, assimilators, convergers, and accommodators.

A study done by North Carolina State University [4] on 1000 engineering students, revealed that 46% students were convergers (learning by “doing”), 24% were assimilators, 18% were accommodators, and 14% were divergers.

A slightly different, but related set of learning styles has been described by Felder [5]. This inventory of learning styles is shown in Table I. Students can be classified under these categories by having them answer a questionnaire. These researchers found most engineering students to be active learners, who prefer sensory rather than intuitive information and lean toward visual rather than verbal learning.

Felder also discusses a successful experimentation with teaching styles that comprehensively addresses the learning styles of students [6]. Since any one known learning style is generally not conducive to learning all objectives of an engineering course, this teaching style attempts to address each side of each learning style dimension at least some of the time to strike a balance.

An educational paradigm that has received much attention alongside learning styles is Bloom’s taxonomy of educational objectives [7]. Many educators prefer to at least make use of the principles of the cognitive domain. How this taxonomy can be used in power systems is described briefly next. Following that, the concept of metacognition is explored for use in this same

TABLE I  
FELDER-SILVERMAN MODEL OF INVENTORY OF LEARNING STYLES

Category	Learning Style	
	Active	Reflective
Processing	Learn by doing something physical	Learn by processing information in their heads
Perception	Sensors prefer data and facts	Intuitors prefer theories and interpretation of factual information
Input	Visual learners prefer charts, diagrams and pictures	Verbal learners prefer the spoken or written word
Understanding	Learn by making linear connections between individual steps	Learn by looking at the big picture before seeing the individual pieces

course to help students identify their learning strengths and to strengthen areas where they may be deficient.

## III. BLOOM’S TAXONOMY

Bloom and his colleagues [7], [8] identified three domains of educational activities: cognitive, affective, and psychomotor. Cognitive is for mental skills (knowledge), affective is for growth in feelings or emotional areas (attitude), while psychomotor is for manual or physical skills. While the cognitive domain is most applicable to engineering, parts of the affective domains may also be applied. The psychomotor domain is the least applicable.

### A. Cognitive Domain

One of the most oft-cited documents in educational outcomes [7], the cognitive domain is arranged in six hierarchical levels as shown in Fig. 2. Cognitive learning is demonstrated successively by comprehending information, organizing ideas, analyzing and synthesizing data, applying knowledge, choosing among alternatives in problem solving, and evaluating ideas or actions. From the lowest level of simple recall or recognition of facts, through increasingly more complex and abstract mental levels, to the highest order of evaluation, this domain is predominant in the majority of courses. Table II lists the skills required for each level.

Bloom found that over 95% of the test questions students encounter require them to think only at the lowest possible level—the recall of information.

Developing objectives and testing students in areas that relate to these six levels require some thought. Some examples are given below:

- **Knowledge example**

- Identify the correct unit for active power in an ac power system from the list: var, watt, watt-hour, Volt-amps.  
(Answer: watt—a simple recall is needed).
- Define the term “surge impedance loading.”

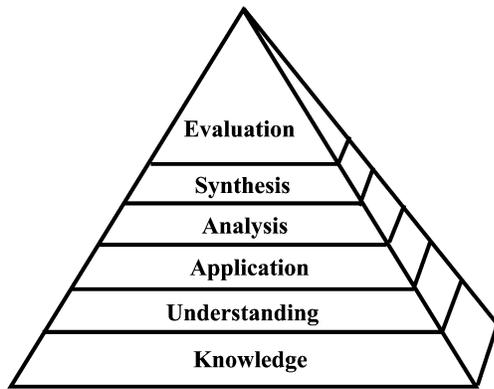


Fig. 2. Cognitive domain in Bloom’s taxonomy.

TABLE II  
BLOOM’S TAXONOMY OF EDUCATIONAL OBJECTIVES

COMPETENCE	SKILLS REQUIRED
<b>Knowledge</b>	<ul style="list-style-type: none"> <li>• Observation and recall of information</li> <li>• Knowledge of major ideas</li> </ul>
<b>Comprehension</b>	<ul style="list-style-type: none"> <li>• Translate knowledge into new context</li> <li>• Interpret facts, compare and contrast</li> <li>• Predict consequences</li> </ul>
<b>Application</b>	<ul style="list-style-type: none"> <li>• Use methods, concepts, theories in new situations</li> <li>• Solve problems using required skills or knowledge</li> </ul>
<b>Analysis</b>	<ul style="list-style-type: none"> <li>• Breaking down information</li> <li>• Organization of parts</li> <li>• Recognition of relationships</li> </ul>
<b>Synthesis</b>	<ul style="list-style-type: none"> <li>• Using old ideas to create new ideas</li> <li>• Generalize from given facts</li> <li>• Relate knowledge from several areas</li> </ul>
<b>Evaluation</b>	<ul style="list-style-type: none"> <li>• Compare and discriminate between ideas</li> <li>• Judge value of theories, presentations</li> <li>• Make choices based on reasoned argument</li> </ul>

• **Comprehension Example**

- Describe the steps you will take to perform a no-load test of a single-phase transformer. What information regarding the transformer do you get from a no-load test?

(Knowledge of facts, theories, procedures, etc. is assumed, and student must demonstrate understanding of this knowledge)

- Explain the effect of field current increase on the armature current of a synchronous generator.

• **Application example**

- A three-phase balanced delta-load of  $90\angle 30^\circ \Omega$  is served by a 480-V source. What is the line current?

(Answer:  $5\angle -30^\circ$ —In order to answer this question, the Ohm’s law in phasor domain must be known and the knowledge of three-phase delta-connected load must be known).

- given system parameters, determine the shunt compensation required to bring bus voltage up to 1.05 p.u.

• **Analysis example**

- Given the converged bus output and line-flow output from a power-flow analysis, verify Kirchoff’s nodal law, that is total power in equals total power out.

(This will require output analysis for real and reactive power lost in the line due to resistance and reactance and reactive power generated by the shunt capacitance).

• **Synthesis example**

- Given the series inductive reactance of a three-phase line as  $0.25 \Omega/\text{km}$ , the shunt susceptance as  $5.7 \times 10^{-6} \text{ S per km}$  to neutral, the line spacing as 12 m, design a two-conductor bundle with the same total cross-sectional area but one that yields a 30% lower series inductive reactance. Make appropriate assumptions.

(This will require working with GMD and GMR of a single conductor bundle and then designing a two-conductor bundle under the constraints given).

• **Evaluation example**

At this level, students may be asked to judge the consistency of an analysis, the validity of an experimental procedure, or interpretation of data. An output from power-flow analysis, or results from a balanced fault analysis, or results of an economic dispatch routine, etc. may be given to them for checking validity of output from the perspective of known principles. For example, in the case of economic dispatch, with three generators participating in dispatch, the power outputs may not satisfy one or more of the constraints. Even if the constraints are met, the output may not make good engineering sense. So, they may be asked to support their answer with arguments.

Setting educational objectives based on Bloom’s taxonomy and applying teaching styles based on the inventory of learning styles appear to be foolproof methods that should guarantee results in the classroom. When things fail, most will point to either that the objectives were not implemented properly or that the teaching and learning styles were not coincident. In these situations, one fails to realize that a third reason could possibly be a learning disability.

It is becoming more evident that student motivation and valuation of subject matter plays a very important role in learning. For that reason, the affective domain and the metacognitive domain must also be targeted.

B. *Affective Domain*

This domain [8] includes the manner in which we deal with things emotionally, such as feelings, values, appreciation, enthusiasm, motivation, and attitude. A goal in this domain might be that “students will appreciate the importance of per unit analysis.” Objectives written for this domain relate to behaviors, which are indications of a student’s attitude, appreciation, or value. There are five major categories in this domain. Only four applicable items that were used in the power course are listed in Table III.

IV. LEARNING TO LEARN AND METACOGNITION

Learning is a process. Those who possess knowledge about how they learn can generally regulate the learning process to develop

TABLE III  
FOUR CATEGORIES UNDER THE AFFECTIVE DOMAIN

<p><b>Receiving:</b></p> <p>Awareness, willingness to hear.</p>	<p><b>Examples:</b> Listen to the instructor and other students with respect. Listen for and remember certain facts and figures presented in class.</p> <p>Learning outcomes: Students may be asked to answer minute-long quizzes during class lecture.</p>
<p><b>Responding to phenomena:</b></p> <p>Active participation on the part of the learners. Attends and reacts to a particular phenomenon.</p>	<p><b>Examples:</b> Participating in class discussions. Giving a presentation. Questioning new concepts, models, etc. in order to fully understand.</p> <p>Learning outcomes: Presenting; reading; reporting</p>
<p><b>Valuing:</b></p> <p>The worth or value a person attaches to a particular object, phenomenon, or behavior.</p>	<p><b>Examples:</b> Demonstrates acceptance or non-acceptance of deregulation in the power industry. Proposes a plan to improve transmission planning under deregulation. Demonstrate awareness of renewable energy.</p>
<p><b>Internalizing values (characterization):</b></p> <p>Has a value system that controls his/her behavior.</p>	<p><b>Examples:</b> Shows self-reliance when working independently. Displays team spirit in groups. Displays ethical behavior.</p>

mastery over complex subject matter. Those who are unable to regulate their own learning often fail because of an inability to direct or redirect their resources. However, sometimes they can be steered, through focused exercises, to identify their own cognitive styles.

A well-known concept that drives the learning to learn idea is “metacognition.” It is a term coined by Flavell [9] and is used to describe a student’s ability to analyze his (or her) own learning and progress. This process requires that a student establish goals and work through strategies to achieve them while doing self-evaluations along the way. Metacognition requires that the student try to identify the process that he (or she) had successfully used in the past and the level of interest and knowledge of the subject presently at hand.

According to Flavell, metacognition can be divided into four distinct aspects: metacognitive knowledge, metacognitive experience, goals, and strategies. Metacognitive knowledge refers to one’s knowledge about the task and its demands, and knowledge about what strategies are likely to be effective in achieving one’s goals. Metacognitive experiences are insights or feelings one has concerning his (or her) knowledge. Such insights can lead one to establish new goals or modify old goals, add to one’s metacognitive knowledge, and influence the activation of both cognitive and metacognitive strategies. Goals refer to the objectives currently at hand and strategies are the specific actions deemed necessary to achieve one’s goals.

### A. Metacognition Example

While preparing for a test, a student will gather the study material. Then he (or she) will analyze and judge its difficulty, and based on this judgment, he (or she) will develop a strategy (study time, group discussions, etc.). The student can then judge whether he (or she) is ready and, based on this second judgment, he (or she) will decide whether to terminate the study or to continue studying. A need might arise to change the strategy that he (or she) has employed. A formalization of the metacognition procedure is shown in Table IV.

As one can see, the metacognitive process requires the gathering of knowledge and then a combination of prospective and retrospective monitoring. The identification of how one learns best is a matter of self-experience and self-discipline. In college, the most common forms of learning occur through some combination of gaining knowledge from instructor (listening to class lecture, one-on-one discussions); from peers (peer discussions, team work, etc.); from laboratory exercises; discussion with other professors; by reading (required textbook, other books, technical journals, trade magazines); from multimedia (power-point lecture slides, software, etc.); by doing homework and other problems; by studying homework and test solutions supplied by instructor; by studying old “files” provided by former students; and so forth. Outside of these common vehicles of learning, many engineering students will learn best by feedback on their performance, either through personal communication or by clearly identifying the mistakes made on any problem or written assignment. It is quite obvious that, without feedback, “perfect” lectures could be recorded *a-priori* and used repeatedly via tapes and DVDs without ever having to pay for a live instructor’s services.

## V. ILLUSTRATION

The course “Power System Design” at the University of Missouri-Rolla is a Junior level course offered every semester. It is considered a “power elective” in as much that all students have to take either this or an electromechanics course. Therefore, we get our mix of motivated and nonmotivated students. Most students will only take one power course in a 128-h curriculum and that makes it all the more important to make the course worthwhile for the students. There were 35 students enrolled in the Fall semester of 2002.

### A. Awareness and Valuation of Power Systems

Right off the bat, on the first day, students were given an assignment to answer a set of exploratory questions on some of the history and characteristics of power systems. They were given a week to submit answers by e-mail. The questions were:

- 1) AC versus dc—why is ac the prevalent form of transmission?
- 2) 60 Hz versus 50 Hz—why is 60 Hz the frequency of choice in the U.S.?
- 3) Remote versus generation within load centers. Why are large generators located at remote locations?
- 4) Interconnected versus isolated utility operations. Why are utility companies interconnected?

TABLE IV  
METACOGNITIVE PROCEDURE EXAMPLE

Behavior	Actions
Problem orientation behaviors	<ul style="list-style-type: none"> <li>• Initial reading of the problem</li> <li>• Examining conditions of the problem</li> <li>• Constructing representation of the problem</li> </ul>
Problem solving behaviors	<ul style="list-style-type: none"> <li>• Making a generalization</li> <li>• Making a deduction</li> <li>• Checking computation</li> <li>• Recalling similar problem</li> <li>• Drawing diagrams</li> <li>• Making a guess and checking</li> <li>• Searching for pattern</li> </ul>
Domain-specific behaviors	<ul style="list-style-type: none"> <li>• Performing computation/procedure</li> <li>• Recalling a fact</li> </ul>
Metacognitive behaviors	<ul style="list-style-type: none"> <li>• Stating a plan</li> <li>• Clarifying task requirements</li> <li>• Reviewing progress</li> <li>• Recognizing error</li> <li>• Detecting new development</li> </ul>

Such questions serve as an initiation into the practice of power engineering, and, at the same time, provide motivation to continue to look farther. By participating in this activity, students are answering the question of “why” certain things are as they appear to be. These are common sense ideas that just need to be investigated in some detail. Most of these concepts are usually accepted at face value and not given a second thought by most students. Students submit their responses via e-mail which makes it easier to respond quickly. After students submit their answers, they are asked questions, such as: Why do you think so? What resources did you use? Did you think thoroughly? Are you satisfied with your answer? Is the answer logical? Will the answer sound logical to someone else?

This example relates directly to the “valuing” category of the affective domain indicated in Table III as well as to the “metacognitive behaviors” as shown in Table IV. Operational reliability and efficiency of power systems took years to develop to what they are today. Students realize this fact while trying to answer these questions. Some can also recognize, with some help, the flaw in their erroneous arguments.

Fig. 3 shows a sample of answers to the first two questions as submitted by students.

*B. More Challenging Assignment*

The first set of preliminary questions is followed up by questions of moderate difficulty and need some background of physics and electromagnetics. The goal is to enable students to tie concepts learned elsewhere to concepts in power. Some example questions are:

- Why does line resistance increase with temperature?
- Explain the reason behind electromagnetic propagation of power. [Why does power travel in any one direction (i.e., sending to receiving end while both voltage and current are ac?)]

Question No. 1: Why is AC the prevalent form of transmission?

Logical and reasonable answers

Transformers and induction motors made generation and transmission at high voltages more convenient and since transmission at higher voltages has less loss, AC became the more attractive choice. A problem that made DC less attractive was the production of harmonics in the line that required filtering. However, when considering great distances, DC could be more advantageous in some cases.

Not so logical and reasonable answers:

AC is the prevalent form of transmission because a DC line carrying the power needed by a single community would need to be extremely thick and much heavier than the AC wires. AC wires can carry the same amount of power with larger voltages and much lower currents.

Question No. 2: Why is 60 Hz the frequency of choice in the US?

Logical and reasonable answers

1. In order to interconnect different sources, the frequencies needed to be the same. A standard was then created. The US chose 60 Hz.
2. Tesla invented electric motors which operated at 60 Hz. When he went to work for Westinghouse, these motors would not work on their 133 Hz AC systems. Therefore, Westinghouse was forced to switch to the 60 Hz system. This has stuck throughout the years, even though the rest of the world has 50 Hz systems.

Not so logical and reasonable answers:

1. 60 Hz is more dangerous to humans than 50 Hz.
2. 60 is a number that is easily divisible and so makes some calculations easier
3. 60 Hz is easier to produce into a smooth DC current.
4. The US uses 60 Hz simply to be more efficient in the generation and the utilization process. Also, the lower frequency puts more stress on electric motors.
5. The US uses 60 hertz because lower frequencies operate at greater efficiency, and frequencies lower than 60 can cause lights to visibly flicker.

Fig. 3. Sampling of answers from students in responses to the first two research-type questions.

These types of questions serve as examples of “synthesis” that appear in Table II.

The answers to these questions are left up to the reader to explore.

*C. Problem Solving*

Although engineering students have come to know and realize that they are being trained to become problem-solvers, many will feel uneasy about a problem they have not seen before. This form of anxiety arises when ample time has not been spent on practicing problem solving. There are some students who might falsely believe that they know how to solve

a problem, but do not take the time to carry out the solution in its entirety. A simple strategy that ought to work under most circumstances is:

- 1) study a problem;
- 2) study a solution pattern;
- 3) solve by hand;
- 4) verify by computer code, if necessary;
- 5) repeat for another problem.

By following this pattern repeatedly during problem solving sessions in class, instructors can expose this strategy to students and some will pick up the idea. Others will eventually figure it out when the stakes are high—(e.g., before a test). This strategy will appeal to both “convergers” (learn by doing) and “assimilators” (learn by logical thinking).

#### D. Importance of Communication

The various learning styles become apparent after a few weeks of class. Students, in general, like to quietly listen to the instructor during class. They neither feel the urge to ask what is on their minds, nor do they have the real opportunity to raise an issue. However, e-mails and web-based discussions threads provide the perfect medium for many of these students to discuss ideas and questions. Sometimes, they can be encouraged to have one-on-one discussions with the instructor.

In one particular instance, students were given an “extra credit” assignment wherein they could receive points equivalent to one homework grade. This came in handy for students who missed an assignment for whatever reason. The extra credit assignment was to browse a three-volume short course CD [10] on reserve at the library and search for a specific answer. In this media, the speaker (Dr. Wollenberg) talks about a particular line in Minnesota that gets overloaded during transactions between Manitoba Hydro and Chicago. They were asked to find the name of this line and the context in which the line was discussed. In order to find this information, they had to browse through the set which takes an average of about 2 to 3 h. They were asked to e-mail me (instructor) the answer and then come and meet me in the office to answer a few questions which could only be answered if they had actually viewed the CDs. From discussions with the students who submitted the answers, it was quite revealing to find that they learned a few extra concepts from the CDs that were not covered in class.

Clearly, this was an example of “evaluation” appearing in Table II as well as an example of self-reliance. Students were able to compare and discriminate between ideas presented in class and elsewhere. Some found it even refreshing to hear some of the same concepts but with a different perspective.

The answer to this question is left up to the reader to find.

#### E. Class Project

An important activity that helps students enhance their thinking skills along with their problem solving skills is the class project, such as a power-flow project. Certain things that are emphasized in the project are: individual discussions; learning by doing; creating extreme situations and then figuring out solutions, first by trial and error and observing cause and effects. Then, students are asked to follow up their initial obser-

vations by applying known analytical techniques. These case studies help them understand the power network principles, such as why real and reactive powers may flow in opposite directions on the same line or why a receiving end (load) voltage magnitude may, in fact, be higher than the sending end (generator) voltage. This study gradually builds up to more complex practical design issues, such as designing systems not just for the current operating conditions, but for future load growth and for network element outages. Students are asked to explain why they made the choices.

This project, if done right, exemplifies the gamut of the “metacognitive procedure” enumerated in Table IV. It starts with the student recognizing the problem and the conditions as stated, then making guesses and checking, making generalizations and testing, recognizing errors, and eventually closing out given tasks as they get completed.

Fig. 4 shows a sample of project iterations based on student queries and instructor responses.

#### F. Writing Assignment

The main purpose of this assignment is to measure a student’s success to function in a team. Team assignments can also be made for accomplishing significant tasks which are not entirely covered in class. Each team, made up of four to five members, was given a distinct assignment. In this assignment, they were asked to conduct sort of a survey of electric power generation, transmission and utilization in the U.S. They were asked to identify solutions and provide details in a short report that supports their ideas followed by a logical conclusion. They were allowed to search and access any information source they felt necessary. Each team had a leader who was in charge of delegating responsibilities, such as obtaining specific details, assigning deadlines, creating meeting schedules, etc. Each team member received an identical score. A short (5 min) presentation before the entire class was also required. Through this collaborative learning process, students are likely to attain higher levels of achievement and, thereby, build self-esteem and display a positive attitude to the subject of power engineering. Each individual on the team was also asked to submit a self-evaluation of their activity based on specific questions, such as: What problems were faced by the team? How did the team members learn from one another? What resources were used?

Answers to these questions help the student to realize how each hurdle was overcome and whether this cooperative process lead to enhanced learning.

The following are the assignments and summaries of student responses to the writing assignment.

*Team 1 Assignment: What are some of the challenges for the power industry in the next 20 years? Come up with some credible ideas and expound.*

Students identified power industry deregulation, environmental regulation, energy price volatility because of increasing dependence on natural gas, development of alternative energy resources such as fuel cells and wind power.

*Team 2 Assignment: Discuss the current circuit breaker (CB) types in use today. Compare their characteristics. Discuss the state-of-the-art in CB design.*

**Instructions for Project:**

Given is a 10-bus system. Note the generator buses, transformers locations and shunt reactive compensation already present.

**Part 1.** Obtain a load flow solution. Make sure all bus voltages and line flows are within limits. Use extra compensation, modify MW and voltage schedules, change transformer taps, etc. as needed. Restrictions are: you may not change the load; you must justify the reason. Since there is a cost associated with any change you make, you must include the approximate cost incurred.

**Part 2.** Modify the system (add or remove generators, add or remove branches) so that you can come up with a lowest cost design. Again, restrictions are that you may not change the load; you must justify the reason. Lines cost \$X/mile; transformers cost \$Y/MVA; generators cost \$Z/MW and shunt capacitors cost \$Q/Mvar.

**Queries/Responses/Discussions:****Part 1:**

While doing some of the optimization under the given constraints, slack bus active power may become negative. This condition is unacceptable. Students are also asked to check generator reactive power limits and line losses — two items that are usually overlooked. They must try to keep losses low and reactive power within limits.

**Part 2:**

After a solution is produced, students are asked to change loads, create a line outage, etc. and observe system behavior under each case. They soon realize that although their design may be a least cost solution, both reliability and security may be compromised. Students are advised that load growth can be expected and that most power systems are required to withstand loss of one or two network elements.

Fig. 4. Sample project iterations.

This team showed comparisons of three types of CB in use today for low-, medium-, and high-voltage applications. Advantages and suitability were indicated for oil-immersed, air-blast, and SF<sub>6</sub> breakers. Each has unique characteristics that make it applicable at different voltage ratings.

*Team 3 Assignment: Discuss the impact of high-voltage transmission (electromagnetic fields) on health—make arguments on both sides of the issue.*

Extensive research in the past has led to inconclusive results. They looked at summary reports from the US committee on Interagency Radiation Research and Policy Coordination; the Australian Ministry of Health; the National Radiological Protection Board of the U.K.; the Danish Ministry of Health; and the French National Institute of Health and Medical Research. A significant outcome of various research studies is that even though scientists failed to find a conclusive correlation between EMF and health, most of them refused to certify that it was safe to live near a high-voltage (HV) power line.

*Team 4 Assignment: If your team was given the charge of improving the power system infrastructure, what are the steps you would take? What would be your estimated budget? Provide details about your choices.*

Improving power quality and increasing transmission capacity were listed at the top. Solution strategies

discussed were use of distributed generation and the addition of transmission lines between strategic locations. Estimated cost—\$13 billion!

*Team 5 Assignment: Blackouts, where entire regions (consisting of several states) will go dark for many hours is rather infrequent. However, they are a possibility. Find out possible reasons for such blackouts. Describe one such blackout that happened in the U.S. in the 1990s decade.*

Students in this team identified that interconnections between generating plants and multiple load centers may lead to cascading failures of various components under severe emergencies. They listed two events—1996 Western U.S. blackout due to summer heat and the 1998 Northeastern U.S. blackout due to ice storms. They discussed the main reasons and concluded that even though blackouts are unavoidable, their impact can be minimized.

*Self-Evaluations:* In response to the self-evaluation questionnaire, almost every student complained that finding time to do this team assignment was a problem. Setting up team meetings was also cited as a problem. One problem that most students had to overcome was lack of background. Some said that the assignments were vague in nature and just too broad. Focusing on a few important points was rather difficult. At the end though, they all realized that they could overcome most of these problems by persistence and effective teamwork.

Some recalled knowledge in other classes during group meetings; some recalled experiences from internships. Some had asked acquaintances in the power industry. Each individual searched for specific information. Then, the team sat together to compare notes. The report was then compiled by an individual and revised at least once by another individual.

Not surprisingly, students found the Internet to be the most convenient resource to use for this assignment. However, some also used textbooks and trade magazines.

### G. Assessment of Learning

The question of whether learning has occurred is usually measured by performance on tests and quizzes. However, test scores do not necessarily indicate learning. Often mean and median scores of a statistical class compared to a similar statistical class in other semesters can be used as one of the indicators. Even then, because of random fluctuations, it is difficult to accept these results. While the cognitive skills have traditionally been measured by written samples, written tests, problem solving exercises, interviews, etc., there are no standardized tests for measurement of metacognitive skills. Some have proposed observing attitude and behavior toward learning a skill or a concept as a good measure. Since learning can usually be related to how students value the material they learn, it makes sense to observe some quantitative figures, such as:

- number of students who decided to drop the course midway through the semester.

None of the 35 students who were enrolled on the first day of class had dropped this class. The class average grade after the final examination was 3.0 out of 4.0.

- number of students who will go on to take a second power course.

Out of the 35 students in the class, 17 students opted for a second elective power course in the following semester.

- number of students who consider power as a career option.

On the final day of classes, during teacher evaluations, the students were given a set of questions to answer regarding the course. The choices given and the (anonymous) number of respondents within parentheses were:

- 1) I like power. I would like to become a power engineer (20).
- 2) I really don't like power. I sort of felt forced to take this course (6)
- 3) I didn't like power at the beginning of the semester. Now I do! (4)
- 4) I thought I liked power at the beginning of the semester. Now I don't! (1)

Four students did not answer.

## VI. DISCUSSIONS AND CONCLUSIONS

For whatever reason, many college students have difficulty in figuring out a "right" strategy to learn in the many courses they take. Even after the instructor adopts good instructional practices that supposedly help students learn content specific information, learning may not occur fully unless a student learns to monitor his (or her) own learning. Nonetheless, strategies may be adopted by instructors that can help foster the development of learning strategies. This type of strategy includes activities that encourage valuation, appreciation, enthusiasm, motivation, and attitude.

The metacognitive process requires the development of judgment of learning and a feeling of knowledge. Information must be processed effectively to become knowledge and knowledge must be organized and accessible to be used [11]. Students need opportunities for practicing their learning strategies. This can happen via proper testing at the various levels of Bloom's taxonomy. Generally, with guided practice and measured feedback, students can polish their skills. It is also ultimately true that there is no substitute for hard work.

Certain practices that the instructor can adopt in a power engineering class to enhance both teaching and learning experiences are described below.

- Encourage teamwork, student-student discussion; student grading.
  - assign in-class team quizzes. Each team works on specific problems. Example: Given a three-bus system, set up the admittance matrix. How does the matrix change if a transformer is added? What happens if a constant power load is added at a bus? What about a constant impedance load?
  - Assign out-of-class team projects with the requirement that team members select a leader and the leader assigns individual responsibilities. The team meets occasionally to discuss viewpoints. At the end, each member writes his (or her) assessment of the experience—be it good or bad.
  - Ask students to evaluate each other's project work, term paper, and project presentation if suitable.

- Keep students prepared by frequent quizzes that will not only test their preparedness but also their ability to think. These quizzes do not necessarily have to be too complicated or mathematically intensive.
  - Example 1: A person measures the voltage and the current at a well pump (motor). His (or her) measurements show 120 V(rms) and 6 A(rms). So he (or she) assumes that the power consumed by the pump is 720 ( $120 \times 6$ ) W. However, when he (or she) measures the power at the pump with a power meter (wattmeter), to his (or her) surprise, he (or she) finds the reading to be 575 W. What could be the reason for this discrepancy assuming that all instruments are in perfect working condition?
  - Example 2: A new load (saw mill) is to be connected to a utility substation at a distance of 1 km through a single feeder. The substation's nominal voltage is 34.5 kV. The motors in the saw mill are all rated at 480 V and are rated to collectively draw 100 kVA. How will you connect the saw mill to the substation? You should specify the approximate ratings and location of each piece of equipment that you will use. Explain your choices. What approximations or assumptions did you make?
- Content structuring
  - Conventional wisdom is to follow a logical sequence of content progressively building on material learnt in previous chapters—the so-called "deduction" method of teaching. This method is the most commonly followed paradigm because most textbooks follow this structure. One drawback is that some students do not always see the "big picture" until later in the course by which time they might have lost interest.
  - An alternate method would be to start with the finished product—perhaps a simplified but complete system—and then discuss how each individual pieces fit together to form a fully functioning, engineered system emphasizing specific theoretical background and practical skills. A computer-based project could be started early either in a laboratory environment or as part of a class project that requires students to gradually build up a power system with necessary operating and reliability constraints. This form of "discovery" learning can be very effective in some cases.
- Student participation
  - Build confidence through in-class and electronic discussions on issues related to homework, practice problems, and other assignments.
- Student leadership
  - Ask students to rotate project leadership among team members.
- Helping students take initiatives
  - Ask students to devise a new plan, modify a piece of equipment to enhance its functionality, interview an industry professional, and report in class, etc.
- Helping students make self-assessment
  - Ask students individually, preferably via e-mail, to describe how he (or she) learned a complex concept,

such as a power factor control in generators, or per unit computations in a power network with transformers.

- Ask students to discuss why any one concept was just too complex to fully grasp .
- Building student attitude
  - Applaud each individual student for excellence in performance in tests, project, homework, library assignment, written paper, etc. A sense of accomplishment is a great motivator.
  - Point out weaknesses in case of poor performance and encourage extra reading or writing assignments, extra credit homework, etc. to make up work. Every one deserves a break or two.
- Building student persistence
  - Ask students to do at least two drafts of term papers. Students should be given feedback on what needs to be improved each time. Keep track of changes made to each draft.
  - In some special situations, ask students to submit answers only to homework problems. Allow them to resubmit answers until they get it right.
- Challenging students
  - Power systems exhibit nonlinear behavior because of various operating and physical constraints applied to all pieces of equipment—saturation characteristics of magnetic cores, real and reactive limits of generators, line limits, transformer tap limits, the core requirement to maintain bus voltages around nominal, and so on. This is the reality of engineered systems. As such, challenges abound in designing and operating a reliable power system. Questions that test a student’s comprehension of the material should not be merely numerical problem-solving exercises. Certain questions should be posed to probe deeper understanding, which require both synthesis and evaluation based on reasoned argument. Equipment sizing, line/transformer placement and design, evaluating alternate scenarios in each design, etc. provide some opportunities to test the depth of knowledge.
  - Ask students to find business opportunities in the new market-based economics as opposed to cost-

based economics. Profit motivation in this discipline is just as vital as in any other business. What factors determine price of electricity? What is involved in owning and operating a merchant plant? What value-added services could be provided to customers that might generate additional revenues?

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