12-1-2002

# Applying Learner-Centered Pedagogy to an Engineering Circuit-Theory Class at Smith College

Susan E. Voss
*Smith College*, svoss@smith.edu

Glenn Ellis
*Smith College*, gellis@smith.edu

# APPLYING LEARNER-CENTERED PEDAGOGY TO AN ENGINEERING CIRCUIT-THEORY CLASS AT SMITH COLLEGE

*Susan E. Voss[1] and Glenn W. Ellis [2]*

**Abstract** — . *This paper discusses examples of learner-centered activities that have been incorporated into a circuit-theory course at Smith College. The learner-centered activities are organized around the structures of community, knowledge, and assessment. Specific examples include the use and ongoing development of "Concept Tests," frequent assessment of the students and the course, a peer-editing process facilitated by using class time to edit lab reports, and discussions and readings related to the social context within which electrical engineering concepts reside. This course is part of a program-wide effort to integrate learner-centered pedagogy into the entire engineering science curriculum.*

*Index Terms ¾ Circuit theory, learner-centered, ABET 2000, assessment*

## INTRODUCTION

Based upon a strong foundation of research, the National Research Council (NRC) [1] has reported that learner-centered environments are an essential element for a high quality learning experience. Defined by the NRC as "environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting", it is clear that new pedagogical approaches are required in the classroom. The NRC reports that successful pedagogy must engage the initial understanding and experiences that students bring to the classroom, build upon and organize their learning through the context of a conceptual framework, and empower students to take control of their own learning.

In addition to learner-centered environments, the NRC also discusses the importance of "knowledge-centered" and "assessment-centered" environments. According to the NRC, a knowledge-centered environment "helps students acquire the knowledge and skills necessary to function effectively in society," and "take[s] seriously the need to help students become knowledgeable by learning in ways that lead to understanding and subsequent transfer." Knowledge-centered environments encourage metacognitive student behavior with students "expecting new information to make sense and asking for clarification when it does not." In an assessment-centered environment, assessment that is congruent with student learning goals is used to provide opportunities for feedback and revision.

None of the environments act in isolation. All relate to developing an effective community of learners. Figure 1, adapted from references [1] and [2], schematizes how these environments might relate to each other and to the community as a whole. At Smith College, a partnership between the Department of Education and Child Study and the Picker Engineering Program has been formed to implement these ideas throughout the nascent engineering science program. Concept and skills mapping is being used to develop and coordinate classes as well as facilitate metacognitive learning. In these classes learner-centered pedagogy will largely replace lecture as the primary teaching tool.

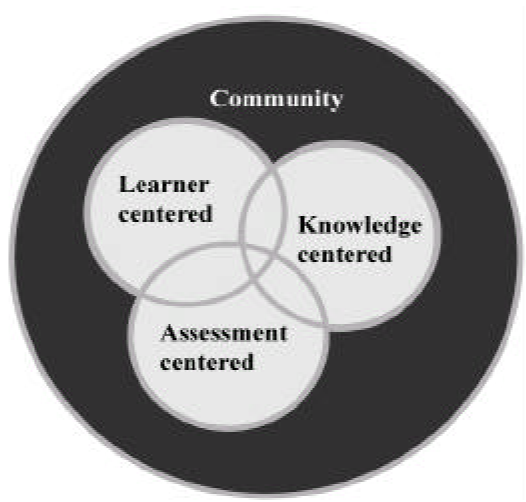


Figure 1
RELATIONSHIP BETWEEN THE LEARNING ENVIRONMENTS THAT FOCUS ON COMMUNITY, THE LEARNER, KNOWLEDGE, AND ASSESSMENT. ADAPTED FROM [1] AND [2].

The Picker Engineering Program, established in 2000, is the first engineering program at an all women's college in the United States. In addition to educating technically competent engineers, this program also aims to educate socially conscience engineers who will integrate engineering with the sciences and humanities. Indeed, Picker Engineering Program Objectives (i.e., in the context of ABET 2000) include a broad sense of social relevance, with graduates considering the impact of their professional actions on society and applying their engineering education in service to humanity.

1 Susan E. Voss, Smith College, Picker Engineering Program, Little House, Northampton, MA 01063 svoss@smith.edu
2 Glenn W. Ellis, Smith College, Picker Engineering Program, Little House, Northampton, MA 01063 gellis@smith.edu

## COURSE OVERVIEW

The circuit-theory course, EGR 220, is a required course for the engineering science B.S. degree and is taken primarily by engineering majors. Some of the students expect to attend graduate school in electrical engineering and other students have no intention of future study in this general subject area. Thus, the course must be rigourous in covering appropriate technical topics while simultaneously engaging effectively a student population with diverse goals.

Specific technical topics covered by this course are consistent with those found in most traditional undergraduate circuit-theory courses, usually taught through an electrical engineering department. Specifically, the course includes a description of the basic circuit elements (e.g., resistors, capacitors, inductors, op amps), basic analysis techniques (e.g., Kirchoff's Laws, Nodal and Mesh Analysis) and theorems (e.g., linearity, superposition, Thévenin equivalent), time domain analysis of first- and second-order circuits (source-free and forced responses), and the concepts of impedance and sinusoidal steady-state analysis, frequency response and transfer functions. In addition to these traditional circuit-theory topics, EGR 220 has several activities and approaches that are incorporated into the course structure to create a learner-centered environment. It is these additional topics that form the basis for this report.

EGR 220 is a "work in progress" in that it has been taught a single time (Spring 2001) with eleven students. We report our current ideas for integrating learner-centered pedagogy into this class, but we also emphasize that we expect to continue changing and building upon the structure reported here. For example, the objectives for the course were modified after the course was taught, and we report the current wording of the course objectives.

Students taking EGR 220 are expected to learn:

(1) to analyze analog circuits that include energy storage elements in the time and frequency domains, both theoretically and experimentally;
(2) the fundamental principles in electric circuit theory so that they can extend these principles as a "way of thinking" to solve problems in mathematics, science, and engineering;
(3) how to improve their oral, visual, and written communiction skills;
(4) how to work efficiently both individually and in groups;
(5) to think about the social context within which electrical engineering fits; and
(6) to evaluate their personal understanding of the concepts and ideas discussed in the class.

## COURSE SPECIFIC LEARNER-CENTERED ACTIVITIES: COMMUNITY FOCUS

The community is inseparable from a learner-centered environment (Figure 1). This community component includes the classroom, the school, "and the degree to which students, teachers, and administers feel connected to the larger community of homes, businesses, states, the nation, and even the world" [1]. As faculty in this program, we strive to develop courses that develop both a "community of learners" and individuals who are reflective and informed about their world community. Thus, there are two broad areas in which learner-centered community activities reside: "the community of learners" and "the societal community." Here we describe current activities within EGR 220 that relate to these two areas of community.

### Laboratory report peer editing

There were three formal laboratories and accompanying reports associated with the course. Each student wrote her own laboratory report. Peer editing of these reports was organized and facilitated for the second two laboratory reports, and this approach will be used for all laboratory reports the next time the class is taught. Specifically, one week before the report's due date, a class period was dedicated to editing the reports. Each student brought two copies of her report to class: one copy for a peer editor and one copy for the instructor to edit. At the beginning of the class period, a short class discussion focused on the positive and negative consequences associated with both giving and receiving constructive criticism; this discussion was initiated by showing a transparency of a heavily edited page of scientific writing from the instructor's research writing. The goal of this discussion is to help students feel comfortable making suggestions to others and also receiving criticism without feeling attacked. In future years, we plan to assess, via questionnaires, whether or not this type of discussion is effective. Overall, the students who came to class with entire rough drafts of their laboratory reports clearly benefited from the peer-editing process; the students who came minimally prepared benefited somewhat less.

### Laboratory report group presentations

After each of the three laboratories and the reports were completed, an assigned group of three to four students designed and presented a poster presentation on the laboratory. These informal presentations allowed for discussion of the laboratory after it was over so that students had a second chance to think about the topics. They also provided a sense of community in that an assigned group of students helped the entire class to understand the laboratory more thoroughly.

### Grade assignments

To encourage a sense of community, it was made clear that grades would not be assigned on a curve and that in fact it was possible for all students to earn an "A" (or a "C").

### Class discussions related to electrical engineering and society

Two specific class discussions focused on issues that relate to the social context within which electrical engineering fits. The first discussion was based on assigned readings about the public debate on "DC" versus "AC" electricity delivery at the end of the $19^{th}$ century and the roles played in this debate by Thomas Edison [3] and Nikola Tesla [4]. Through this discussion, the students became aware of the meaning of "DC" and "AC" and some qualitative fundamental differences between the two types of signals. Additionally, the students engaged in enthusiastic discussion about the political atmosphere surrounding the debate and the questionable ethics in the approaches of specific individuals to convince the public of a particular point of view. A second discussion involved the energy crisis in California. The students read a review of the current situation [5] and the class discussed issues relevant to deregulation, including how our society relies on energy in the form of electricity and how we generate and deliver this energy. A homework problem related to this discussion helped students estimate the amount and cost of electricity they used in their dormitory rooms, and it asked them to "write a carefully-constructed paragraph that describes the amount of energy you use in your dormitory room to someone who is not familiar with electric energy or power. Put your description in terms of a quantity of energy that the person can picture." One student's responded as follows.

> "The amount of energy that I use in my room each month is approximately equivalent to the energy dissipated if 17 kg of coal is burned. This amount of coal can be fitted into three recycle bins of approximate dimensions of 1ftX1ftX0.8ft. … The typical coal burned in power plants in the United States has an energy content of 24 kJ/g, and the efficiency of such power plants is 30%. So 450 grams of coal (about a bottle of jam) produces 1kWh of energy. Therefore, about 17 kg of coal produces 38.1 kWh of energy, which is the energy I estimated to be consumed in my room during a month" [6].

Both classroom discussions were popular with students (based upon course assessments), and introduced them to both societal issues as well as developed conceptual understanding of basic terms in circuit theory (e.g., DC, AC, power, energy) by employing multiple intelligences.

### Solar energy lecture and project choice

A traditional circuit-theory class provides ample background for students to understand how solar energy might be used to power numerous applications. One class period was devoted to developing concepts of solar energy and solar cells, and eight of the eleven students (two groups of four students each) chose to base their final project on a solar-energy-related topic. One group designed a system to run a lap-top computer in a remote area with no possibility of connecting to an electrical grid. The second group connected a 100 W solar panel to the grid through an inverter and analyzed the amount of power the solar cell was actually returning to the grid. The inclusion of solar-energy concepts relates a largely theoretical circuit-theory course to both societal issues and more practical applications of the theory that students with limited exposure to circuit theory can understand.

### Summary

The examples discussed above illustrate some possibilities for connecting individual students with their peers in the learning community and also with the larger community in which they will live and practice. This approach utilizes pedagogy that has been shown to be effective and that engages multiple learning styles and intelligences (and therefore a more diverse student population). It is also consistent with meeting the need for educating engineers who work effectively in diverse groups and understand the impact of their actions in a societal and global context.

## COURSE SPECIFIC LEARNER-CENTERED ACTIVITIES: KNOWLEDGE FOCUS

Key to a knowledge-centered environment is helping students to build effectively upon the experiences that they bring into the classroom. While such an approach will affect every part of a course, the initial focus in EGR 220 has been to encourage and assess conceptual understanding and to identify common student misconceptions.

### Concept Tests

The term "Concept Test" [7] refers to a short conceptual question often asked during lecture to assess student understanding. Students are typically asked to think about the question for a few minutes and to then discuss the question with other students sitting nearby. After the brief group discussions, a student is asked to go to the board and to present her explanation of the question. Whether or not the answer is correct, and sometimes with assistance from the instructor, the student entertains questions from others and essentially leads a group discussion of the question. Currently, in EGR 220, we try to include at least one concept test per 50-minute lecture period, and we expect to add more in the future. However, many of the current questions are similar to traditional homework problems, and we are in the process of developing questions that focus more on the relevant concepts. As an example, we show one concept test (Figure 2) developed during EGR 220.

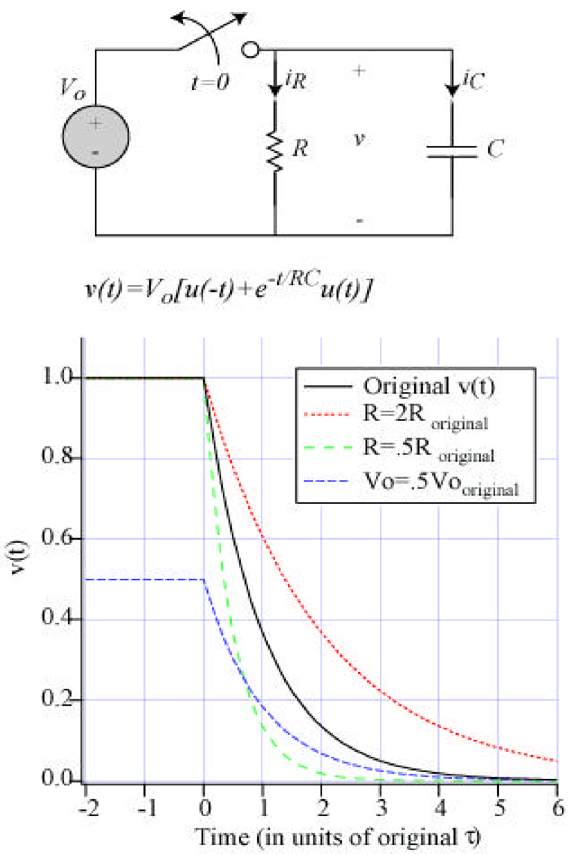


FIGURE 2
EXAMPLE OF A "CONCEPT TEST" [7] DEVELOPED FOR EGR 220. IN THIS CASE, STUDENTS EXPLORE HOW THE VALUES OF THE RESISTANCE AND THE CAPICITANCE AFFECT THE TIME CONSTANT AND OVERALL RESPONSE OF THE CIRCUIT. THE LEGEND IN THE LOWER GRAPH IS COMPLETE HERE, BUT STUDENTS MUST MATCH THE APPROPRIATE RESPONSE TO THE APPROPRIATE SITUATION.

### Discovering initial student understanding and misconceptions and helping students build upon this knowledge

We are in the process of identifying misconceptions that students bring to the classroom. For example, it became clear that some students were timid and uncertain about using laboratory equipment (e.g., oscilloscopes, power supplies, voltmeters, etc). In the future, we plan to develop a brief laboratory-safety discussion that will allow all students to feel informed and safe during the laboratories. A second misconception we have discovered relates to the general concept of "What do electrical engineers do?" During the first lecture, we led a discussion about this broad topic and discovered that several students related electrical engineering only to the work of electicians and the electrical wiring of buildings. Thus, while the students had a general idea of one area of electrical engineering, they had little idea of the larger picture. We plan to build upon their knowlege in this area by frequently including examp les of the diverse areas that employ skills related to electrical engineering. A final type of misconception relates to misconceptions generated within the classroom. In particular, many topics that we teach within a circuit-theory course include substantial jargon (e.g., "AC," "DC, "open circuit," "short circuit," "kill the source," etc.). It is important to emphasize to the students which terms are merely jargon and to reinforce the typically simple meanings for the jargon.

## COURSE SPECIFIC LEARNER-CENTERED ACTIVITIES: ASSESSMENT FOCUS

To establish an atmosphere in which students have multiple and diverse opportunities to demonstrate concept mastery, grading does not depend heavily on a single exam or assignment (Table I).

TABLE I
COMPONENTS OF EGR 220 THAT DETERMINE A STUDENT'S FINAL GRADE.

| | |
|---|---|
| Homework (weekly) | 5% |
| Weekly Homework Quizzes | 15% |
| Hour Tests (3) | 30% (10% each) |
| Laboratories (3) | 15% (5% each) |
| Lab Poster Presentation | 5% |
| Design Project | 10% |
| Final Exam | 20% |

### Weekly homework and quizzes

Students are encouraged to work together on weekly homework assignments, and each homework assignment is followed with an in-class weekly quiz that lasts about 10 minutes. The students are told explicitly that the purpose of the quiz is to assure that they understood the fundamental concepts in the homework assignment, so that if a student understands the concepts in the homework assignment, then she should perform well on the quiz. This interaction between weekly quizzes and homework assignments leads to an environment where it is possible to encourage students to work together on homework assignments but at the same time hold each student responsible for assessing her personal understanding. This practice is consistent with the goal of a knowledge-centered environment where students become metacognitive in that they are able to assess their understanding of a subject area. Part of the development of metacognition requires student reflection of their performance. In this case, we showed the class a plot of individual quiz grades versus homework grades (Figure 3) to help them assess their approaches to homework assignments. If homework and quiz performances were perfectly correlated, then all points would fall on the dotted line. In fact, there is scatter in the data--the meaning of which was the focus of a class discussion. Points that fall below the dotted line might suggest that a student's homework performance may exceed her actual understanding of the material; this situation could occur if a student engages in group work to complete the homework assignment but in fact does not contribute to solving the problems in a substantial manner. Alternatively, points that fall below the line could also indicate poor test-taking ability, possibly as a result of anxiety related to the quiz. Points above the line might indicate that the student has mastered the concepts, but that her problem solving skills (or effort) do not match her conceptual understanding. As long as a student performs well (e.g., perhaps above 80%) on the quiz, it is not a concern when the homework grade is lower than the quiz grade.

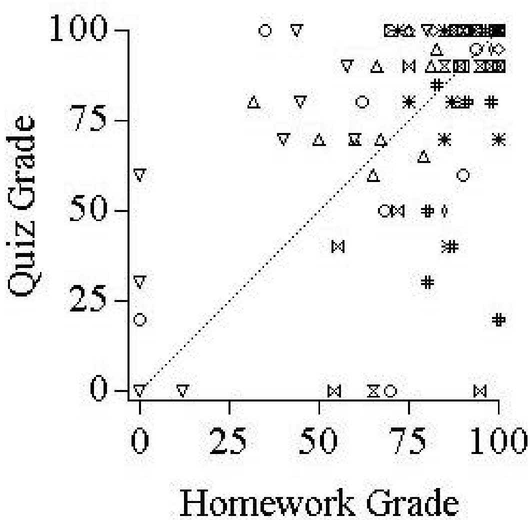


FIGURE 3
SCATTER PLOT COMPARING GRADES ON HOMEWORK ASSINGMENTS TO GRADES ON THE CORRESPONDING WEEKLY QUIZ (N=10). EACH SYMBOL REPRESENTS A DIFFERENT STUDENT (N=11). THE DOTTED LINE INDICATES POINTS FOR WHICH THE HOMEWORK GRADE AND THE QUIZ GRADE ARE EQUAL.

**Corrections on exams**

Three exams were administered during the semester-long course. After the first two exams were graded, students were given the option to correct their mistakes and re-submit their exams with corrections. The exams were then regarded and corrections allowed students to earn up to 50% of the points they did not earn the first time (e.g., a student earning a grade of 50% could improve to 75% by answering correctly all questions on the exam). [Corrections were not an option on the third exam due to its proximity in time to the final exam.] Figure 4 demonstrates that most students took advantage of the opportunity to correct their exams, which allowed them multiple opportunities to demonstrate concept mastery.

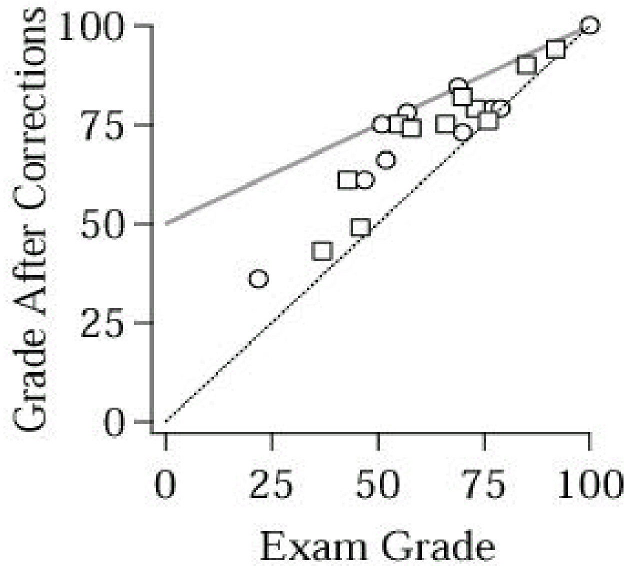


FIGURE 4
SCATTER PLOT COMPARING EXAM GRADES TO EXAM GRADES AFTER STUDENTS RECIEVE 50% OF ANY UNEARNED POINTS AFTER MAKING CORRECTIONS. THE DOTTED LINE INDICATES POINTS FOR WHICH THE EXAM GRADE AND THE GRADE AFTER CORRECTION ARE EQUAL, AND THE SOLID GRAY LINE INDICATES THE MAXIMUM GRADE POSSIBLE AFTER CORRECTIONS WERE MADE.

**Course Assessment**

Three questionaires were administered to the class during the semester: one at the beginning, one mid-semester, and one near the end. The feedback from these questionairres was and will be used to revise some aspects of the course. Some of the key findings of the mid-semester and final questionaires are listed here. (1) In response to the open-ended question "How are the lectures working for you? Do they include too much or too little discussion?", two of ten respondents suggested 80 minute lecture periods instead of 50 minutes periods because they felt that the amount of discussion was helpful but with this style there was not enough time to cover all topics in 50 minutes. We have changed the course schdule so that it will now meet for 80 minute periods. (2) Nine out of ten respondents liked the computer-projected lectures, which included a partial handout of the lecture and was projected to the white board so that some analysis was performed with a traditional "chalk-board" approach; we will continue this approach and comment that students are of course encouraged to take their own notes if they prefer. (3) The course syllabus included a list of required reading for each class period, and the instructor constantly reinforced the importance of reading ahead. Eight out of ten students reported that they read the assigned material in the text book before the class, and the other two students reported that they sometimes read. (4) Students generally felt lost during the final laboratory (series RLC circuit) and suggested that a pre-laboratory introduction would be helpful. We plan to develop materials to provide an introduction to the laboratory assignments; however, we will have to find a balance between the student-desired "cook-book approach" and our desired, albeit more time consuming, "discovery" approach.

## WHERE DO WE GO FROM HERE TO DEVELOP FURTHER A LEARNER-CENTERED ENVIRONMENT?

### Learner-centered: Community Focus

We plan to continue the activities described above that relate to community focus (i.e., peer editing of laboratory reports, group presentations of laboratory reports, emphasis on not grading on a curve, discussions on topics that relate electrical engineering to our social structure, and opportunities to learn about alternative energy sources such as solar energy). The largest change that we foresee in this area is that we need to emphasize and focus more on the peer editing. Students generally found this process helpful, but not all students came well enough prepared to benefit from the sessions.

### Learner-centered: Knowledge Focus

We will continue to develop concept tests and to further indentify misconceptions that students bring to the classroom. Classroom activities and homework will be designed to address these misunderstandings and take advantage of the learning opportunities that they present. Additionally, we have many ideas that are currently being developed. In particular, we are working to develop a "course road map" that will represent pictorally (e.g., flowchart style) the concepts and skills in the course and how they relate to each other. In this way, the instructor can periodically refer to the "road map" so that the students are able to appreciate the bigger picture and how it relates to a single day's topic. Concurrent with the development of this course road map, we are also developing a strand map [8] that will provide a detailed mapping of how various strands of concept and skills are developed and interrelate in our program. This map will be fundamental to learning by helping students understand the big picture, understand and construct their knowledge within a conceptual framework, assess their progress and set learning goals, and see how apparently unrelated subjects share common fundamental principles. For example, the connection between circuits analysed in EGR 220 and the vibration of mechanical systems covered in other engineering courses--as well as the reliance of both subject areas upon an understanding of differential equations—will be addressed in each course.

### Learner-centered: Assessment Focus

We will continue the assessment practices discussed above, as well as some additional ones. Each time we teach the class, we will benefit from new student comments and also from student reactions to changes we make in the class (e.g., pre-laboratory introductions and increased lecture periods). At the program level we plan to include student portfolios as the central tool for encouraging metacognitive assessment. Intensive assessment of student knowledge, attitudes, and actions will also be conducted at the program level and provide feedback to measure how EGR 220 is functioning within the entire learning sysem.

## SUMMARY

All of the ideas presented in this paper are geared toward applying to circuit theory what the research has shown to be most effective for student learning in any situation. Community, knowledge and assessment are all important focuses of a learner-centered environment. For the learner, community ranges from student peers in the immediate learning community to society in the global community. To properly develop content knowledge, classroom activities and assignments must build upon the experiences that students bring to the classroom. Concept tests can support this approach. Assessment through varied measures should be chosen and implemented to enhance metacognitive learning.

## REFERENCES

[1] National Research Council, *How People Learn: Brain, Mind, Experience and School*, Washington, DC: National Academy Press, 2000.

[2] Bransford,, J.D., "Designing environments to reveal, support, and expand our children's potentials", *Perspectives on Fundamental Processes in Intellectual Functioning* (Vol. 1), Soraci, S.A. and McIlvane, W., eds. Greenwich, CT: Ablex, 1998, pp. 313-350.

[3] Flatow, I., "The War of the Currents, or Let's 'Westinghouse' Him, *They All Laughed*, Harper-Perennial Edition, 1993, pp. 27-44.

[4] Metzger, T., "The Wizard" and "The Transformer", *Blood and Volts*, Autonomedia, 1996, pp. 49-91.

[5] Time Magazine, "The new energy crunch", January 29, 2001, pp. 37-48.

[6] Toor, F., Response to homework assignment #1 Problem A, Smith College, Course EGR 220, February 7, 2001.

[7] Mazur, E., Peer Instruction, Prentice Hall, Inc., 1997.

[8] American Association for the Advancement of Science, Atlas of Science Literacy, Project 2061, Washington, DC, 2001.