Introduction to systems approach using bio-energy resources as a tool for freshman engineering education

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***Abstract* – A workshop module was created to introduce freshman engineering students to sustainable energy scenarios by means of concepts of systems. The module was also designed to represent spiraling of key concepts the students were introduced to, prior to the workshop activity. Berkeley-Madonna, a dynamical simulation software, was utilized to simulate and compare two future scenarios of power production met by coal and bio-diesel, respectively. Student understanding of the scenarios was evaluated by subjecting the students to five pre- and post-test survey questions set up on a 5-point Likert scale. Statiscal repeated-measures analysis was performed on a much smaller set of data than expected due to insufficient post-test responses. Analysis of the pre- and post-test data indicated a significant difference and improvement in response to only one of the five questions posed, which assessed the individual student's apriori knowledge on "carbon sequestering" and "carbon neutral policy"**

Index Terms – Berkeley-Madonna, Spiraling curriculum, Sustainable Energy, Systems Concept

INTRODUCTION

Virginia Tech's College of Engineering has had a general engineering program for freshman since 1968 for all the 1200 students in the college. The content and delivery of instruction has undergone significant modifications after Fall of 2000. With a large freshman engineering class, it is a challenge to provide a meaningful hands-on experience. In addition, it is a challenge to integrate the first year experience with upper level courses in the ten degree granting departments. To improve the freshman engineering program, the Department of Engineering Education submitted proposals to NSF. The first project "Bridges for Engineering Education at Virginia Tech" was awarded in Fall of 2003 and became a planning project for the second funding from NSF for departmental level reform (DLR). This DLR project, funded in Fall 2004, focused on reformulating the engineering curriculum for specifically bioprocess engineering program in the Department of Biological Systems Engineering in conjunction with the freshman program in the Department of Engineering Education and School of Education [9].

The primary goal of the DLR grant is to create a theme based spiral curriculum that integrates the freshman engineering and bioprocess engineering curricula with the broad aim of integrating the freshman program with all engineering majors in the College. Systems approach is one of the three important themes in the project. The other two are design and ethics. To teach the concepts of systems approach to freshman students, the faculty planned to include several activities. In Fall 2005, students were introduced to a water tower experiment where in which a hand-on activity involved on studying the flow through an orifice. The container had a truncated cone (bucket) shape to provide a changing volume with height. This provided some geometrical calculations to compute volume and flow on paper using theoretical equations. The students had also chance to see the change in velocity as the water drained from the tank. They collected the height in the water tank with time and had worked on developing predictive equations to fit the data. Later part, students were introduced to the model of the same system using Berkeley Madonna software to display the use of specialized simulation program. Changing the variables like the dimensions of the tank, orifice diameter on the fly to see the effect on flow was demonstrated. The students were asked to reflect on the reason for differences between their predictive equations and Torricelli's equation for flow [3]. In addition to the water tower experiment, during Spring 2006, the energy demand and use of bio-based energy resources was selected to demonstrated the systems concepts to the students. This paper describes this effort in detail.

In a dynamically changing world of finance and businesses, meteorological phenomena, ecology, and energy consumption and production, it is essential that scientists of the future understand the concept of dynamics and the impact of variables in a constantly evolving system.

Current world scenario is focused on dwindling energy resources and the impact of their usage on the environment. The United States faces serious shortage of energy in the future with its ever increasing demand for fossil fuels. The consumption of fossil fuel in the United States is 25% of the total world consumption, despite a population of only 4.7% of the world population [12]. The coal supply in the United States is projected to last less than the estimated 100 years mainly due to its depleting oil resources and its growing

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population that is projected to double to more than 500 million in the next 60 years [12].

Combustion of fossil fuel also releases drastic amounts of CO_2, a major greenhouse gas, into the atmosphere. Fossil fuel resources in the world today can produce 5000 gigatons of carbon (GtC), with a world consumption of 6GtC per year [8]. Due to deforestation and reduction in soil fertility due to intensive agriculture, the concentration of CO_2 in the atmosphere has been increased [11]. It is essential that in the future, for a healthy economic growth, the atmospheric CO_2 is stabilized using a "carbon-neutral" method of energy consumption.

In the last few decades, energy modeling has been widely utilized for energy policy analysis mainly to evaluate the effects on economy and find means to reduce expensive oil imports [10]. Technology-oriented optimization models and economy-oriented models were two models that were utilized for analysis of the energy sector and its importance on the overall economy. One of the earliest models, the Brookhaven Energy Systems Optimization Model (BESOM) has been responsible for the development of more sophisticated models today that also incorporate global warming [10].

Our study involves incorporating a simple time-dependent model in a hands-on workshop module to expose engineering freshman to sustainable energy scenarios through means of utilizing systems concept. The assignment module was incorporated in the freshman engineering course titled ENGE 1024: Engineering Exploration in the Spring session of the year 2007. Developing problem solving and critical thinking skills and early exposure to engineering design activities are tackled in the course. In recent years, a number of innovative hands-on workshop activities have been introduced into the ENGE1024 course with the aim to excite freshmen about the engineering profession and to provide early exposure to the issues in the future.

The module was also based on a spiraling curriculum concept. The twentieth century psychologist, Jerome Bruner, proposed the concept of the spiral curriculum. Bruner advocates that a curriculum as it develops should revisit the basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them [1]. The basic objective of the module was to enable the students to dynamically visualize changes in systems by altering the variables. Students utilized simulation software used for analyzing time-dependent relationships called Berkeley-Madonna, to evaluate two separate scenarios involving coal and bio-diesel as energy sources in the future.

METHODOLOGY

Students enrolled in the ENGE 1024 course had been exposed to previous energy-related lectures and workshop activities. The module was created to reinforce the concepts that the students were previously exposed to in order to implement the spiraling curriculum concept in the module. These previous energy-related activities included

- Video on sustainable energy and carbon sequestration provided by Dr. Ishwar K. Puri from the Department of Engineering Science and Mechanics,
- Hands-on world map activity to expose students to population growth and energy consumption,
- Sustainable energy design term project.

In addition to the above, the module also comprised of problem-solving skills, graphing skills, and flowcharting, that the students were exposed to priori through homework assignments and workshop activities.

The module was implemented in the following manner as mentioned below

- Pre-workshop survey
- Pre-workshop flowchart assignment
- Pre-workshop lecture on systems and energy
- Pre-workshop reading literature on Berkeley-Madonna simulation software
- Hands on workshop activity using Berkeley-Madonna simulation software
- Post-test survey

Pre-workshop Survey: An optional pre-workshop survey included 5 questions that the students filled on scan-tron sheets. The pre-workshop survey was completed by the students on April 2nd 2007 during their lecture session.

The questions were addressed evaluate and assess individual students' knowledge on current energy scenarios. The survey was completed during the lecture session of the ENGE 1024: Engineering Exploration course The survey questions were designed on a 5-point Likert scale (1- Strongly Agree, 2- Agree, 3- Neutral, 4- Disagree, 5- Strongly Disagree). The questions posed to the students were designed based on a possible change in response after the activity was completed. The questions posed to the students were as follows,

Q1. So far, you have participated in various energy-related activities in this course. For example, Dr. Ishwar Puri's video, world map activity, sustainable energy design project. I think I'm aware of critical energy-related issues in the world today.

Q2. The only way to ensure that our non-renewable energy resources (coal, oil, natural gas, etc.) can last longer than predicted is to control our ever-growing population.

Q3. I believe that in the future, crop-based fuels (e.g., bio-ethanol and bio-diesel) alone can alleviate the United States' energy demand and dependence on foreign oil sources.

Q4. I am aware of the terms "carbon sequestration" and its impact on implementing a "Carbon Neutral Policy."

Q5. Assuming that we have enough vegetation in the world today to absorb current CO_2 emissions. I think this vegetation cover will be sufficient to absorb CO_2 emissions for the next 10 years.

Pre-workshop flowchart assignment: Pre-workshop assignment consisted of two flowchart problems based on energy scenarios, which were to be assigned as homework.

The first problem involved a sequence and selection structure to compare CO_2 emissions between two fictional power generation companies with a given clientele population. A fictional government agency was included in the assignment that gave tax-breaks on the profit generated to the company that emitted lesser CO_2 emissions when compared and charged an additional percentage on the company with higher emission.

The second problem involved a sequence and repetition structure that was used to predict the generation of a soybean crop-based bio-diesel, land area requirement, and CO_2 sequestration by the crop area for a given time period for an exponentially growing human population and demand.

The flowchart problems were created to prepare the students for the workshop activity and gain some knowledge on "carbon sequestration" and "carbon neutral" concepts.

Pre-workshop lecture: Students attended a special guest lecture on systems concept and renewable energy issues, created and presented by Dr. P. Mallikarjunan. The students were given basic background on systems and different types of systems and how the concept could be applied to energy-related issues in the world today

Pre-workshop reading assignment: A document giving students some background on the activity along with a brief discussion on the two scenarios, viz., coal and bio-diesel, which were being simulated using the Berkley-Madonna software. Included in the document was introductory information on Berkeley-Madonna software, explained with reference to a previous workshop problem-solving activity which involved attempting to fit an empirical function of the height of standing water in a draining bucket with respect to time. Also included in the document were instructions for uploading the simulation software on the students' tablet computers. The students were required to read the assignment prior to their workshop session.

Workshop activity using Berkeley-Madonna: The workshop activity was conducted on April 5th and 6th of 2007 during the workshop sessions. Each session had approximately 30 students and students were asked to work in pairs. The Berkeley-Madonna executable file and two model files for simulating the coal and bio-diesel scenarios were made available for download on ENGE 1024 website for the activity. The two scenarios assumed 50% process efficiency and that 20% of the energy demand in the future was met by coal or bio-diesel. For creating the model files, data for population, energy usage, forest and land area were collected from various U.S. government websites [2, 4, 6, 7, 13-16].

The coal model (Figure 1) simulated forest area required to sequester CO_2 and its comparison to forest area growing naturally by means of a surplus/deficit variable. The bio-diesel model, on the other hand, simply compared the bio-diesel requirement by a growing population versus bio-diesel generated through existing crop land using a similar surplus/deficit variable. The bio-diesel source for the simulation model was assumed to be soybean derived. Research indicates that 1g of soybean oil, undergoing a conversion process similar to saponification, produces 1 g of bio-diesel [16].

The model responses were varied by using pre-designed sliders to increase or decrease variable values. The worksheet involved filling in blanks combined with some minor problem solving activities. Students were expected to complete the assignment in full to obtain an activity grade.

Equations used in modeling: For both coal and bio-diesel energy scenario models, the population growth was based on the growth model indicated in the equation below

$$P = P_o e^{rt} \tag{1}$$

Where, P= estimated population after t years
P_o= current or initial population
r = population growth rate

The forest growth rate for the coal model was derived from nonlinear mixed models of forest growth prediction [5], given by

$$\frac{dF}{dt} = F_{eq} kn\left(1 - e^{kt}\right)^{n-1} e^{-kt} \tag{2}$$

Where, n = growth index
k = growth rate
F_{eq} = equilibrium growth potential for the forest
F = forest growth

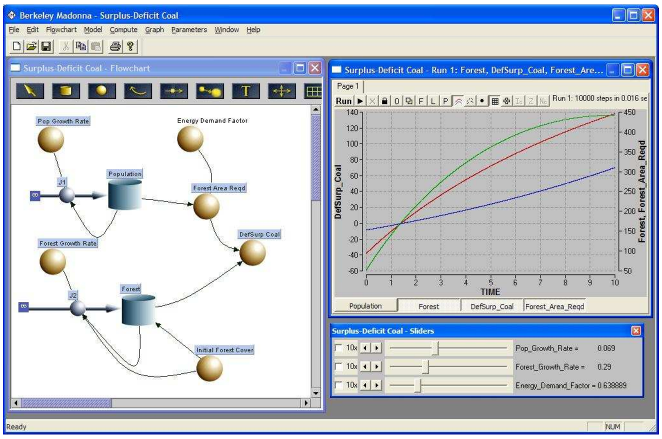

FIGURE 1
SYSTEMS SOFTWARE VIEW OF COAL DEMAND

Post-workshop survey: The post-workshop survey was conducted on May 1st 2007. The same five pre-workshop questions were posed to the students as post-test questions. It was expected that there was an "improvement" in response, in terms of knowledge gained, from the questions.

RESULTS AND DISCUSSION

Due to time constraints, only one of the flowchart problems created as a pre-workshop activity was assigned as homework. The students completed the homework and submitted it during the workshop session which involved the proposed activity.

The workshop activity was conducted and aided by the graduate student who developed the exercise module and teaching assistants who served as workshop leaders. Students were also allowed to bring in their pre-workshop literature on the activity to aid them in completing the assignment. Students were able to complete most of the assignment in class despite some difficulty in grasping the concept of the exercise initially. All students were allowed to finish the exercise at home and were able to submit the completed worksheet during the following week. Students were also encouraged to offer feedback in writing to improve the exercise for the Fall Semester.

The models used for simulation and the workshop activity were not actual representations, but simplified versions of complicated models to reinforce the idea about sustainable energy. While the initial models for simulation were constructed using data for the United States, the students were able to utilize the variable sliders in the software to explore scenarios for other countries as well.

Data Analysis: Data analysis was performed on the Likert scale responses of the students' response to the five questions posed in the pre- and post-workshop surveys. Since the survey was considered optional, in accordance with the rules of the Internal Review Board at Virginia Tech, out of a total strength of approximately 180 students in the ENGE 1024 course, only 82 students participated in the pre-workshop survey. However, due to the tragedy at Virginia Tech during the third week of April, the post-workshop response during the lecture session on May 1st was limited to 28 students. Among these 28 responses, only 17 of them were considered for analysis since only these students had taken the pre-workshop survey.

Table I gives the modal value of responses in the pre- and post-workshop responses to the questions in the order listed in the methodology section, based on the Likert scale

TABLE I
MODAL VALUE RESPONSES OF PRE-AND POST-WORKSHOP SURVEY

Question	Pre-workshop response	Post-workshop response
Question 1	Agree	Agree
Question 2	Disagree	Disagree
Question 3	Agree	Agree
Question 4	Disagree*	Agree*
Question 5	Disagree	Disagree

The only change in modal response was observed in question no.4 posed to the students. The data was then subjected to a repeated measures analysis to find any statistical differences between the pre-and post-workshop responses. Table II indicates the P-value of the ANOVA analysis performed (α=0.05) on the responses of each question using MS Excel™.

TABLE II
P-VALUES FOR ANOVA ANALYSIS ON PRE- AND POST-WORKSHOP RESPONSES

Question	P-value
Question 1	0.78
Question 2	0.50
Question 3	0.06
Question 4	0.00*
Question 5	0.88

It can be indicated that question no. 4, which assessed the student's knowledge on carbon sequestration and carbon neutral policy showed a statistically significant improvement in response. Approximately 71% of the 17 students, who had answered "Disagree" or "Strongly Disagree" to this question prior to the workshop, answered "Agree" on their post-workshop responses.

Analysis and Discussion on responses: It was rather remarkable to notice that all of the 17 responses to question no. 1, which assessed the student's awareness on critical energy-related issues were in the "Agree" or "Strongly Agree" categories during the pre-workshop survey. The post-workshop response to this question changed three responses from "Agree" to "Strongly Agree", indicating an improvement in the response. Approximately 60% of the responses to question no.2, which dealt with the student's assessment on the longevity of current non-renewable resources, were answered "Disagree" or "Strongly Disagree" in the pre- and post-workshop responses. Approximately 83% of the responses for question no.3, which assessed the student's capability to predict whether crop-based bio-fuels could alleviate dependence on foreign oil were answered in the "Agree" category in the pre-workshop survey and three responses in the post-workshop survey changed from "Agree" to "Disagree." Approximately 76% of students responded "Disagree" or "Strongly Disagree" to question no. 5, which dealt with the student's ability to predict if the vegetation cover in the future would be sufficient to sequester CO_2. In the post-workshop response to question no. 5, three of the responses were changed to "Neutral" and two of them to "Strongly Disagree", after these students had answered "Disagree" on the pre-workshop survey.

It is clear from the response pattern for questions no.1 and 2, that the workshop did not significantly improve the response, indicating that the individual under study was more aware of energy-related scenarios and the dwindling resources of fossil fuels in the world today. Question no.3 did not show an improvement in response either, since the exercise was constructed to show that vast amounts of land would be needed to meet the demand for power generation, which could not be practically met with a growing population's need for shelter and food. Despite the fact that there was no change in response for question no. 5, the students were correct in assessing the ability of the vegetation cover to exist in the future to sequester CO_2, indicating their awareness on deforestation. Though not very significant, the change of response from two students from "Agree" to "Strongly Disagree" indicated a positive influence due to the workshop activity.

CONCLUSION

While the workshop was implemented successfully, attested by positive student responses in terms of feedback, extenuating circumstances forced the study population to reduce in size during the post-workshop survey session. From the nature of responses, it can be deduced that questions 1, 2, and 5 were inherently not successful in posing a question whose response could be altered during a post-test. While question 3 did not show improvement, it can be based largely on the student's inability to respond to the question correctly based on the knowledge gained while performing their workshop activity. These changes will be considered by the authors when the module is applied to a larger student population during Fall semester later this year. Assessment data indicates that a larger participating group could provide better analysis of the study.

Suggestions are being made to improve the exercise based on the feedback and include a post-test exercise prior to the survey and to make the survey available online. The exercise showcased the spiraling concept successfully by incorporating various aspects of the course being revisited in the different components of the module. More approaches like these, combined with pre-existing teaching modules are required to improve the freshman engineering student's ability to grasp basic concepts and become more aware towards a multi-disciplinary approach.

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