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A Case Study on Problem-based Learning in a Bio-resource Optimization Course*

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Problem-based learning (PBL) is an instructional strategy that challenges students to 'learn and apply a process' to real-world issues by using a problem situation to focus the learning activities. This paper describes a case of PBL for a group of students in the Bio-Resource Optimization course. With minimal help from the instructor, the students brainstormed on potential problem areas to choose a specific problem for their course project. This paper describes the problem adopted by the team and the results of their work. Results showed that PBL is an effective tool for learning.

Keywords: PBL; bio-resource; food science; resource constraints; modeling

INTRODUCTION

NON-RENEWABLE RESOURCES—their availability is always a major concern in any human endeavour. Economic viability, environmental quality, sustainability and competitiveness all require that resources be used in the most efficient way possible within a complex web of physical, socioeconomic, cultural and technological factors. The course entitled 'Bio-Resource Optimization (BE 431)' equips biosystems engineering students with analytical optimization skills to solve complex real-world problems for sustainability, global competitiveness, environmental integrity and resource-use efficiency. The course teaches knowledge and skills in understanding, modelling and solving problems with resource constraints. For example, water, a threatened resource due to pollution, is a complex system comprising multiple and multipurpose reservoirs and on-stream activity [1, 2]. The planning and management of water systems often involve the establishment of optimum operating policies and trade-off between different objectives, such as hydropower production, drinking water supply, irrigation, flood control, wildlife preservation, fish culture, recreation and navigation. Land, another threatened resource due to growing urbanization, is laden with demands for recreation, food production, housing and public infrastructure. An optimization model determining the best combination of livestock enterprises, lease-hunting enterprises and vegetation management practices that maximized discounted net returns was used in the cross-timbers region of the Ozark plateaus [3]. Additionally, irrigation and food are resources that can benefit from optimization [4, 5].

On the corporate side of the world, high performing companies constantly look for new opportunities to create strategic competitive advantage. They constantly change their mix of resource allocation to achieve strong customer relationships, reduce cost, build product awareness and enhance their reputation for quality. In order to respond to perpetual competitive change, winning companies are adopting new tools for overall leadership, vision, direction and resource allocation. Profit is optimized when resource allocation decisions are made, implemented and revisited in concert with complex internal and competitive environments. Allocation of available resources to quality, cost, time and information must be kept in balance. This is done amid separate, often competing, viewpoints. Conventional strategic planning processes are not enough. Optimizing profit in the context of environmental friendliness and social responsibility requires effective additional tools that better integrate the business direction within the competitive culture. These and many other scenarios require that we prepare Biosystems Engineering (BE) students to help identify optimum strategies.

PROBLEM-BASED LEARNING

Problem-based learning (PBL) is an instructional strategy that challenges students to 'learn and apply a process' to real-world issues by using a problem situation to focus the learning activities [6, 7]. The goal of PBL is to provide students with an active role in learning and to let the students take responsibility in learning [8]. The goal of cooperative learning (CL) is to have students work in teams to learn from each other and collectively accomplish the task assigned to the group [8, 9, 10].

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Now we describe a case of PBL for a group of students in the Bio-Resource Optimization course. With minimal help from the instructor, the students brainstormed on potential problem areas to choose a specific problem for their course project.

CASE STUDY

Early in the semester, students are taught general project management and optimization techniques through lectures [11, 12]. Then they work in groups of three to identify and solve complex real-world problems using the techniques learned. Students work with real clients to apply the formulation process, namely:

1. define the problem;
2. identify the decision variables;
3. formulate the objective function;
4. formulate boundary constraints.

Students then translate the problem into mathematical optimization models. The models are solved using any of the recommended solvers, such as Excel, Mathematica or MATLAB. Students present their findings through an oral presentation and a written technical paper. Examples of optimization projects that have been studied, with client names generalized, are listed in Table 1.

To illustrate the problem-based approach, an edited version of the ice cream production problem (Table 1) is presented. This problem was identified, formulated and solved by a group of three students enrolled in the course for autumn semester 2003 [13]. The illustration is excerpted from the student paper, and modified when necessary to clarify the points.

Define the problem

For their project, a group of three students addressed the problem related to the Michigan State University Dairy Store. MSU is one of the few campuses in the nation that operates and manages its own independent dairy plant and store. The MSU Dairy Store offers a selection of dairy products for sale to customers, including 27 different flavours of half-gallon ice cream. These ice cream products are displayed in a sales cooler that has a capacity of 120 half-gallons. The cooler has five shelves, each shelf contains six columns of half-gallons, and each column has four rows of half-gallons, that is, the dimension can be taken as $5 \times 6 \times 4$. This layout allows potentially 30 different flavours to be visually accessible to the customer. In the current layout, 27 different flavours have one column each and vanilla has an additional three. Based on data gathered, this layout does not reflect consumer demand and hence is deemed inefficient. Occasionally, some flavours completely sell-out before they are restocked. On the other hand, other flavours stay in the cooler for weeks before being sold. Since ice cream needs to be scheduled at least a week in advance, the store is losing potential sales for items that are constantly sold out.

The students gathered actual data on the number of half-gallons of each flavour sold over a one-year period, including sales volume, production costs and prices. The students calculated the sales average for each flavour as half-gallons per day for the season from a composite data of the three months involved in that season (Table 2). For example, the summer season included June, July, and August; autumn season, September, October, November; winter season, December, January, February; and spring season, March, April, May.

Corrections were made to 'sold out' or missing data by using the previous month's information. As shown in Table 2, the summer season had the most ice cream sales per day. For all seasons, vanilla was the most popular followed by chocolate, black cherry, butter pecan, mint chocolate chip and chocolate choc chunk in that order. Peppermint stick was popular during the winter and sherbets (lime and orange) were popular only during the summer and autumn seasons. Data also showed that the selling price for a half-gallon was either \$4.00 (£2 approx.) or \$4.50 (£2.25 approx.) per unit during the data period. The estimated production cost was variable due to the ingredients in that flavour; flavours that included nuts or fruit

Table 1. Examples of optimization problems studied by students in BE 431

Topic	Objective	Client	Technique Used
Ice cream production	Max profit	Local dairy store	Linear programming
School lunch formulation	Min cost	Elementary school	Linear programming
Campus bus routing	Min cost	Campus bus	Linear programming
Menu formulation	Min cost	Dormitory cafeteria	Linear programming
Classroom scheduling	Max student time	Elementary school	Linear programming
Police force scheduling	Min cost	Police department	Linear programming
Textbook ordering	Min ordering cost	Local bookstore	Goal programming and linear programming
Healthcare personnel scheduling	Min personnel cost	Health centre	Linear programming

Table 2. Seasonal daily sales average (sold/day) and unit profit for each ice cream flavour

	Flavor	Sales Average, S_i				Profit, P_i
		Summer	Fall	Winter	Spring	
1	Banana Choc Chunk	0.45	0.28	0.26	0.28	2.50
2	Black Cherry	1.27	0.87	0.81	0.92	2.50
3	Blue Moon	0.70	0.43	0.45	0.50	2.75
4	Butter Pecan	1.31	0.87	0.77	0.78	2.25
5	Chocolate	1.19	0.75	1.16	0.85	2.75
6	Chocolate Almond	0.76	0.64	0.59	0.55	2.25
7	Chocolate Chip	0.63	0.31	0.14	0.39	2.50
8	Choc Chip Cookie Dough	0.83	0.55	0.36	0.61	2.50
9	Chocolate Choc Chunk	1.14	0.71	0.89	0.70	2.50
10	Coconut Chocolate Almond	0.54	0.36	0.27	0.26	2.25
11	Coffee	0.72	0.46	0.13	–	2.75
12	Cookies N Cream	0.97	0.56	0.72	0.48	2.50
13	Lemon Custard	0.70	0.36	0.50	0.64	2.75
14	Lime Sherbert	0.38	0.33	–	–	2.75
15	Mint Chocolate Chip	1.24	0.72	0.76	0.97	2.50
16	Mint Cookies N Cream	0.81	0.49	0.42	0.44	2.50
17	Orange Sherbert	0.31	0.27	–	–	2.75
18	Peanut Buttercup	0.85	0.72	0.45	0.77	2.50
19	Peppermint Stick	–	0.13	0.81	–	2.50
20	Pistachio Nut	0.84	0.50	0.26	0.35	2.25
21	Praline and Cream	0.53	0.42	0.32	0.28	2.25
22	Purple Planet	0.36	0.17	0.22	0.33	2.50
23	Raspberry Choc Chunk	1.00	0.68	0.51	–	2.50
24	Strawberry	1.08	0.45	0.53	0.81	2.50
25	Toffee	0.42	0.24	0.39	0.28	2.50
26	Vanilla	3.86	2.28	2.65	1.96	2.75
27	White Chocolate Rasp Heart	0.55	0.38	0.54	0.54	2.50
	Total half-gallon units	23.44	14.93	14.91	13.69	

cost more. Holding a product in inventory also had a cost. The cost per day for one unit in the freezer was \$0.01 (0.005p approx.). Overhead cost was set at \$70.00 (£35 approx.) per flavour/per day, to take account for salary of the workers, cost of energy for the freezing equipment and cost of packaging. Based on the selling price and cost, unit profit was calculated and shown in Table 2. For purposes of this optimization problem, unit profit was defined as selling price minus cost of ingredients per half-gallon.

Identify decision variables

After interaction with the dairy store, the students decided to formulate the production problem using linear programming technique. They decided that each flavour could occupy one, two or three columns according to present practice. The students defined the decision variables as F_{ij} (Flavour "i" occupying j columns in the sales cooler, $i=1, \ldots, 27$; $j = 1, 2, 3$). If $j=1$, the number of half-gallons available to the customer would be 4 (remember, one column held four half-gallons). If $j=2$, the number of available half-gallons would be 8, and if $j=3$, the number of available half-gallons would be 12. Furthermore, the students decided that not all 27 flavours needed to be produced every season. To take advantage of customer preference, some flavours would have to be produced more often.

Formulate the objective function

The students decided that the objective function was to optimize the cooler space by maximizing the unit profit (P_i) of each flavour. The sales average per flavour (S_i) was normalized from 0 to 1 and used as a demand multiplier in the objective function. The formulated objective function is shown in Table 3.

Formulate boundary constraints

The students identified boundary constraints in the cooler layout. Firstly, each flavour could only occupy one, two or three columns in the cooler (Equation 1). There would be only 27 flavours available (Equation 2). If one flavour occupied two columns, then the maximum number of flavours could not be more than 15 (Equation 3). In the same way, if one flavour occupied three columns, then the maximum number of flavours could not be more than 10 (Equation 4). The total number of available columns would be 30 (Equation 5). The students provided an option to vary the number of flavours produced during each period by introducing a variable X in the constraint function (Equation 6). Implicit constraints (Equation 7) would not allow non-positive values of the decision variables. The students organized the equations for the mathematical solver in the standard form, as shown in Table 3 above.

Table 3. Standard formulation

Maximize $f = \sum_{i=1}^{27} P_i S_i (4F_{i1} + 8F_{i2} + 12F_{i3})$

Subject to:

1. $F_{i1} + F_{i2} + F_{i3} \leq 1 \qquad \text{for } i = 1, \ldots, 27$
2. $0 \leq \sum_{i=1}^{27} F_{i1} \leq 27$
3. $0 \leq \sum_{i=1}^{27} F_{i2} \leq 15$
4. $0 \leq \sum_{i=1}^{27} F_{i3} \leq 10$
5. $\sum_{i=1}^{27} (F_{i1} + 2F_{i2} + 3F_{i3}) = 30$
6. $\sum_{i=1}^{27} (F_{i1} + F_{i2} + F_{i3}) \geq X$
7. $F_{i1} \geq 0, \quad 2F_{i2} \geq 0 \quad F_{i3} \geq 0 \qquad \text{for } i = 1, \ldots, 27$

RESULTS AND DISCUSSION

Table 4 showed the results from the optimization model where the desired number of flavours (X) was chosen as either 18 or 24 flavours. Results showed that the highest selling flavours, such as vanilla and chocolate, were assigned three columns in the cooler every season, regardless on the number of flavours selected. On the other hand, some of the lowest selling flavours were dropped. Seasonal flavours, such as Peppermint Stick, Lime Sherbet and Orange Sherbet, were assigned columns on the season that they were popular. When 18 flavours were chosen, the model allocated three columns every season for the most popular flavours, namely: vanilla, black cherry, chocolate and mint chocolate chip. However, when the user specified 24 flavours, only the two most popular flavours occupied three columns and the other 21 flavours occupied one column each. Results also showed that the cooler layout would need to be rearranged every season.

INSTRUCTOR ANALYSIS

The students were able to address the dairy store problem and appropriately formulated an optimal solution to the use of the sales cooler. The process of data gathering, interaction with client, mathematical formulation of the problem and interpretation of results demonstrated that the students learned the skills taught in class. Furthermore, all the solutions were feasible. All the decision variables were positive valued, satisfying constraint Equation 7. Each flavour was assigned one, two or three columns, satisfying constraint Equation 1. The left-hand side values generated from the model with respect to constraint Equations 2–6 are shown in Table 5 below. All the constraints were satisfied; nothing was violated. The solutions were also

Table 4. Solutions when 18 and 24 different flavours were chosen for the cooler

Flavor Description	18 flavors				24 flavors			
	Sum	Fall	Win	Spr	Sum	Fall	Win	Spr
Banana Choc Chunk	0	0	0	0	1	1	1	1
Black Cherry	3	3	3	3	3	3	1	1
Blue Moon	1	1	1	1	1	1	1	1
Butter Pecan	3	3	1	1	1	1	1	1
Chocolate	3	3	3	3	3	3	3	3
Chocolate Almond	1	1	1	1	1	1	1	1
Chocolate Chip	1	0	0	1	1	1	1	1
Choc Chip Cookie Dough	1	1	1	1	1	1	1	1
Chocolate Choc Chunk	3	1	3	1	1	1	3	1
Coconut Chocolate Almond	0	0	0	0	1	1	1	1
Coffee	1	1	0	0	1	1	0	0
Cookies N Cream	1	1	1	1	1	1	1	1
Lemon Custard	1	1	1	1	1	1	1	1
Lime Sherbert	0	0	0	0	1	1	0	0
Mint Chocolate Chip	3	3	3	3	1	1	1	3
Mint Cookies N Cream	1	1	1	1	1	1	1	1
Orange Sherbert	0	0	0	0	0	1	0	0
Peanut Buttercup	1	3	1	3	1	1	1	1
Peppermint Stick	0	0	3	0	0	0	1	1
Pistachio Nut	1	1	0	1	1	1	1	1
Praline and Cream	0	0	0	0	1	1	1	1
Purple Planet	0	0	0	1	0	0	1	1
Raspberry Choc Chunk	1	1	1	0	1	1	1	1
Strawberry	1	1	1	3	1	1	1	1
Toffee	0	0	1	0	1	0	1	1
Vanilla	3	3	3	3	3	3	3	3
White Chocolate Rasp Heart	0	1	1	1	1	1	1	1

Table 5. Feasibility verification of the solutions in Table 4

	Model output of the left-hand side of the constraint equations							
	X=18 flavors				X=24 flavors			
Constraint equations	Sum	Fall	Win	Spr	Sum	Fall	Win	Spr
$0 \le \sum_{i=1}^{27} F_{i1} \le 27$	12	12	12	12	21	21	21	21
$0 \le \sum_{i=1}^{27} F_{i2} \le 15$	0	0	0	0	0	0	0	0
$0 \le \sum_{i=1}^{27} F_{i3} \le 10$	6	6	6	6	3	3	3	3
$\sum_{i=1}^{27} (F_{i1} + F_{i2} + F_{i3}) \ge X$	18	18	18	18	24	24	24	24
$\sum_{i=1}^{27} (F_{i1} + 2F_{i2} + 3F_{i3}) = 30$	30	30	30	30	30	30	30	30

optimal because any layout other than the solutions shown in Table 4 above would result in total profit less than the optimum values generated by the model.

CONCLUDING COMMENTS

The case study presented in this paper demonstrated the learning process experienced by the students. Problem-based learning was an effective tool for teaching bio-resource optimization to biosystems engineering students. The students acquired optimization skills, including the ability to define problems, express them in mathematical forms and find optimal solutions. It encouraged them to work cooperatively. These skills will prepare the graduates to address the challenges imposed by rapidly expanding food and energy needs and increasing resource demands. Furthermore, these skills will prepare them for lifelong learning beyond the classroom setting.

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