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A Decision Tool for Developing a Course in Engineering Economy

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Abstract

As part of an ongoing research project, we present an initial decision framework built around an integer knapsack model to provide guidance for new (and existing) educators in the field of Engineering Economy. The proposed model accepts inputs concerning an educator's teaching environment and the students' learning environment and provides output via suggested course topics and a syllabus. In the current version of the model, all parameters were derived from survey results. This issue is discussed along with other possible approaches. The model is illustrated with results from a pilot study.

1. Introduction and Motivation

It can be argued that Engineering Economy is a core engineering competency, much like statics, dynamics, thermodynamics, fluid mechanics or basic circuits. All of these subjects, including Engineering Economy, are fundamental sections of the Fundamentals in Engineering Examination (formerly the Engineer in Training Exam), which is the first examination towards earning a Professional Engineer license.

However, unlike other basic courses like statics and dynamics, a variety of academic departments teach their own "version" of Engineering Economy. This is based on results of a survey of teachers of Engineering Economy[7]. These include chemical, civil, computer, computer science, electrical, engineering management, environmental, general, industrial, mechanical and materials science, engineering and technology. Depending on the learning environments, different students from different disciplines may or may not learn the same material. The environments vary for a number of reasons, including (1) curriculum setting; (2) course definition; (3) educator background; and definition of the (4) student body.

New educators in the field of Engineering Economy are often unfamiliar with the Engineering Economy body of knowledge, as they may not have any direct experience or they may have been exposed to the field in a different environment. While it is uncommon for professors to be "trained" in any course that they teach[13], this unfamiliarity may be more prevalent in Engineering Economy due to the wide variety of subject matter taught.

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Take Professor Peter Shull, a member of our research team and currently an assistant professor of engineering at Pennsylvania State University, Altoona. Two years ago, he was assigned to teach Engineering Economy. Despite a B.S. degree in Mechanical Engineering and M.S. and Ph.D. degrees in Materials Science and Engineering, he had not been exposed to the material previously and had no mentor for the subject in his department. Seeking information on what should be taught, he attended the Engineering Economy Division sessions at the American Society of Engineering Education (ASEE) annual conference. At these sessions, he was exposed to other Engineering Economy colleagues and their wide variety of teaching methods and course content. However, no resources were currently available to help him develop and teach his course. Professor Shull exhibits the need for a resource to guide the development of a course in which the faculty member may not have formal training, which is a large motivating factor for this research.

This need for a resource to guide teachers has been highlighted in a number of papers and studies highlighting how doctoral graduates are unprepared for teaching. As Wankat and Oreovicz[13] glumly note, "new faculty are … almost totally at sea when it comes to the day-to-day requirements of teaching." This may be because it can be difficult for new faculty members to get the information they need on a range of issues, including teaching[10].

ASEE recently surveyed engineering assistant professors in the United States[1]. In that survey, new faculty requested that ASEE provide more services, including a mentoring system such that less-experienced professors could receive advice of veteran peers. While many young faculty members have excellent mentors, others have come to rely on trial and error and word of mouth[10]. Torvi[12] provides a summary of graduate teaching assistant training programs that are aimed at providing some guidance to doctoral students in the realm of teaching. However, as noted by Norris and Palmer[9], these programs vary in both length and breadth of material covered and there are few programs, which specifically prepare doctoral students for academia.

In the survey, new faculty also requested that ASEE serve as a clearinghouse for everything from course material sharing, labs and software, to teaching and career management workshops and grant opportunities[1]. Repositories are being provided in selected instances for faculty members. For instance, MIR FacultyOnline[6] is an online source of textbook information for college and university professors. The service provides access to textbook data, including reviews, lists of top-selling titles by course, among other information. The Internet Scout Report[3] states "MIR can be extremely useful, especially for younger faculty or professors tasked with teaching courses out of their field." Despite this new abundance of information available, enabled by the Internet, there is still little guidance offered as to its use.

The framework and model in this paper are an initial attempt at providing a resource for Engineering Economy educators. The current version of the model accepts inputs concerning the educator's teaching environment and the students' learning environment and provides output in the form of suggested course topics like a syllabus. The system in which this model is to operate (the actual resource) is also discussed.

Although this model cannot serve as a mentor for new faculty in the area of Engineering Economy education, it can provide some level of guidance and serve as a clearinghouse for related materials. It is this guidance that is deemed most useful, as it should help improve teaching in this critical subject area by pointing educators in the right direction in terms of course development. According to Wankat and Oreovicz[14,15], good teaching is defined by five basic components, including effective instructional materials and the right course content. Wankat and Oreovicz further note that a course syllabus is an ideal way to begin development of a new course. "A syllabus presents a cognitive map of the course goals and how a course fits in the curriculum… After you have determined your course goals and basic structure, and taken into account your own preferences and style, you are ready to start developing your syllabus"[16]. The output of this model provides suggested course syllabi and teaching materials and thus will help new educators take the first step towards becoming good teachers.

2. Proposed Model

We propose an integer knapsack model[5], which is a classical model in operations research, for determining the best course outline to be followed given a set of inputs from an educator. The knapsack problem may be described as follows: A hiker has a knapsack that holds a certain amount of volume. A number of items are eligible to be packed in to the knapsack; however, not all of the items will fit. Each item has a size and an associated value. The objective is to maximize the value of items chosen to put in the knapsack such that the sum of their sizes is less than or equal to the capacity of the knapsack. The integer knapsack allows multiple, identical items to be placed in the knapsack.

2.1 Model Development

In this application, the knapsack is the syllabus and the items to be placed in the knapsack are course topics. A topic can be put in the knapsack more than once, representing more than one contact hour in the classroom or learning environment. The value of a topic is dependent on the input problem parameters. That is, the given demographics of a curriculum, course, educator and student body will define the value of having a given topic in the course syllabus.

Mathematically, the model may be written as follows:

$$\max \quad \sum_j c_j x_j \qquad (1)$$

$$\text{subject to:} \quad \sum_j x_j \le b \qquad (2)$$

$$x_j = \{0,1,2,3,\ldots\} \qquad (3)$$

where x_j represents the number of contact hours of topic j, c_j is the worth or value of topic j and b is the total number of contact hours available. The decision variable x_j takes on a value greater than zero if the topic is selected to be in the syllabus.

The goal of the objective function, (1), in this model is to maximize the value of the selected topics. The topics are subject to constraints (2) and (3). The second constraint is the "knapsack" constraint which states that the total number of contact hours of topics cannot exceed the allotted number of contact hours, b. If only full contact hours are required (not half lectures on certain topics), then the solution follows the integer constraint of (3).

For a given problem, the topics, or x_j variables, are known, as possible engineering economy course topics. However, the c_j and b parameters are specific to the educator and academic setting. Thus, before solving the knapsack problem, the system must convert the supplied demographic information into the objective function coefficients, c_j. This will be accomplished through an analysis of surveys received in an earlier phase our project. The results of our data-gathering phase will provide a data point for each educator interviewed that relates a set of inputs (i.e., information about the course, curriculum, educator and student body) to a course syllabus. By aggregating the data, a distribution on the topics in the course syllabus can be derived from the given set of inputs. This can then be used to choose a reasonable set of c_j values.

2.2 Model Example

Consider the data gathered from the pilot study by Needy, et al.[7]. In this small study, 27 engineering economy educators with varied backgrounds provided information on their course content. A simple example is built here from that pilot data to illustrate the concept of constructing a knapsack model from the collected data. Solution to the model and its implications are discussed in later sections. It is noted that the data is only a pilot study. Despite its limitations in thoroughness, it allows for the proposed model to be illustrated.

Although the pilot survey requested a variety of information, we only utilize the following parameters as data inputs in this illustrative example to describe the teaching and learning environments: (1) Course department affiliation; (2) Educator experience; (3) Average class size; and (4) Student body makeup. From the educator inputs, the following 26 course topics were identified: (A) Interest Rates; (B) Benefit/Cost Ratios; (C) Present Worth; (D) Depreciation and Depletion; (E) Geometric Gradients and Spreadsheets; (F) Cash Flows; (G) Equivalence Relationships; (H) Replacement, Retirement and Breakeven Analysis; (I) Income Taxes; (J) Rate of Return; (K) Inflation and Deflation; (L) Sensitivity Analysis; (M) Decision Making; (N) Evaluation of Multiple Alternatives; (O) Capital Financing and Allocation; (P) Public Projects and Regulated Industries; (Q) Selection of MARR; (R) Accounting; (S) Uncertainty and Risk Analysis; (T) Estimation; (U) After-Tax Economic Analysis; (V) Corporate Tax Structure; (W) Bonds; (X) Multiattribute Analysis; (Y) Profit Volume Analysis of Production Operations; and (Z) Ranking.

For each of the 27 educators polled in the pilot survey, data was collected on their four data inputs (input categories 1 through 4, as given in Table 1) and the amount of contact hours taught on each subject (Topics A through Z). Next, contact hours were summed by course topic for each of the 27 educators in each of the four input categories. For example, if course topic A (interest rates) was being taught by an educator in an Industrial Engineering Department, who was an Assistant Professor, teaching in a Small Class Size (40 and below) to One Major of students, then 1 was added to course category A for Industrial Engineering (input category 1), Assistant Professor (input category 2), Small (input category 3) and One Major (input category 4). The data from each of the 27 educators was tabulated in this manner and resulted in the aggregate results shown in Table 1.

Input Category	Input Value	Topics and Total Contact Hours
1. Course Dept.	Industrial Eng.	18A, 17B, 17C, 13D, 13E, 13F, 12G, 13H, 14I, 13J, 13K, 11L, 10M, 10N, 4O, 7P, 4Q, 5R, 5S, 5T, 4U, 2V, 2W, 1Y
	Eng. Mgmt.	5A, 5B, 5C, 5D, 5E, 4F, 4G, 4H, 3I, 4J, 3K, 3L, 3M, 2N, 4O, 2P, 3Q, 3R, 2S, 1T, 2U, 1X, 1Z
	Civil Eng.	3A, 3B, 3C, 3D, 3E, 3F, 3G, 2H, 2I, 2J, 2K, 2L, 1M, 1N, 2O, 1P, 2Q, 1R, 1S, 1T, 1U, 1V, 1W
	Chemical Eng.	1A, 1B, 1C, 1D, 1E, 1F, 1G, 1H, 1I, 1J, 1K, 1M, 1N, 1U
2. Educator Exp.	Assistant Professor	5A, 5B, 5C, 4D, 5E, 5F, 4G, 4H, 4I, 4J, 4K, 3L, 3M, 2N, 3O, 1P, 3Q, 1R, 1S, 1T, 1U, 1V, 1W
	Associate Professor	5A, 5B, 5C, 3D, 5E, 5F, 3G, 3H, 5I, 4J, 3K, 3L, 3M, 1N, 1O, 1P, 1Q, 1R, 1S, 2T, 1U, 1W
	Full Professor	17A, 16B, 16C, 15D, 12E, 11F, 13G, 13H, 11I, 11J, 12K, 10L, 9M, 10N, 7O, 8P, 5Q, 7R, 6S, 5T, 5U, 2V, 1W, 1X, 1Y, 1Z
3. Class Size	Small (40 and below)	17A, 16B, 16C, 15D, 14E, 13F, 13G, 13H, 12I, 12J, 12K, 11L, 8M, 8N, 10O, 8P, 8Q, 6R, 5S, 6T, 5U, 3V, 2W, 1X, 1Z
	Medium (41-79)	4A, 4B, 4C, 3D, 3E, 3F, 3G, 4H, 4I, 4J, 3K, 3L, 3M, 2N, 1O, 1P, 1Q, 1S, 1T, 1W
	Large (80 and up)	6A, 6B, 6C, 4D, 5E, 5F, 4G, 3H, 4I, 3J, 4K, 2L, 4M, 3N, 1P, 3R, 2S, 1T, 2U, 1Y
4. Student Makeup	One Major	4A, 4B, 4C, 4D, 3E, 3F, 4G, 4H, 4I, 4J, 4K, 3L, 3M 1N, 1O, 3P, 2Q, 1S, 3T
	2-3 Majors	11A, 11B, 11C, 9D, 10E, 9F, 8G, 8H, 8I, 9J, 6K, 7L, 5M, 5N, 6O, 3P, 5Q, 4R, 4S, 1T, 3U, 2V, 3W, 1X, 1Z
	4 or more Majors	12A, 11B, 11C, 9D, 9E, 9F, 8G, 8H, 8I, 6J, 9K, 6L, 7M, 7N, 4O, 4P, 2Q, 5R, 3S, 4T, 4U, 1V, 1Y

Table 1. Aggregate results from educator pilot survey.

For example, of the 27 surveyed educators, 18 are from Industrial Engineering. In total, these 18 educators taught 18 hours of Topic A. This is aggregate data, but on average, each person taught one class hour of the topic. However, of these same 18 educators, only five class hours of Topic R were taught.

From the surveys, it is also learned that a topic is never taught for more than three contact hours. In this small example, it is further assumed that the minimum engineering economy core is two hours of Interest Rates (Topic A), two hours of Equivalent Relationships (Topic G), and one hour each of Cash Flows (F), Present Worth (C), Rate of Return (J) and Sensitivity Analysis (L). The defined core topics and maximum contact hours become additional constraints in the knapsack model. Essentially, the core requirements force the placement of certain topics into the knapsack, and thus, onto the syllabus. In essence, they partially fill the knapsack. The maximum contact hour limits restrict the number of course topic hours that can be placed in the knapsack.

The core topic requirements and maximum contact hours, presented in Table 1, serve as the database for this example problem. A comprehensive database will be similarly constructed during the full study through an extensive data collection effort. A larger, more comprehensive sample is necessary to accurately model and define the engineering economy core.

To illustrate how the system will work, suppose a new educator accesses the system and provides the following inputs: Assistant Professor teaching in an Industrial Engineering department with a 50/50 mix of 100 Industrial and Mechanical Engineering students. Summing the topic contact hours in Table 1 for these inputs leads to values of: 40A, 39B, 39C, 30D, 33E, 32F, 28G, 28H, 30I, 29J, 27K, 23L, 22M, 20N, 13O, 12P, 12Q, 13R, 12S, 8T, 10U, 5V, 6W, 1X, 2Y, 1Z. These are now to be used as coefficients in the mathematical model, which is written as follows:

max	$40x_A + 39x_B + 39x_C + 30x_D + \ldots + 1x_Z$	(objective function)
subject to:	$x_A + x_B + x_C + x_D + \ldots + x_Z \leq 22$	(contact hour (knapsack) constraint)
	$x_A, x_G \geq 2$	(minimum core requirements)
	$x_C, x_F, x_J, x_L \geq 1$	(minimum core requirements)
	$x_j \leq 3$ for all topics j	(contact hour limits for all topics)

The model is constructed from the database of information and the educator's inputs. The contact hour constraint allows for 22 topic hours to be selected in this example, with no more than three hours selected for any given topic. (Note that the contact hours are specific to quarter or semester systems.) Therefore, the knapsack can be viewed as having space for 22 topic hours. The minimum core requirements force certain topics to be placed into the knapsack. Although limited to three contact hours in this example, the contact hour limits may vary for each topic. It is also important to note that any solution to the example problem will find exactly 22 hours of topics. It is obvious, due to the first constraint, that there can be no more than 22 hours. In addition, there will not be less than 22 hours because the model maximizes value and each topic has a positive value in the objective function.

We intend to elicit responses from experts in the field to determine the proper "value" of placing a certain topic in a course. This will serve two purposes: 1) it will validate the sampling procedure illustrated above, and 2) it will provide a method in which to complete samples if the size is too small.

2.3 Model Solution and Output

The solution of knapsack problems has been a topic of research in the operations research community for a number of years[5]. Although the problem has been classified as NP Hard, meaning no known polynomial time algorithm exists for its solution, it has been shown that the problem can generally be solved quite easily in most situations[2]. Dynamic programming (DP) provides a pseudo-polynomial solution procedure[8]. By large scale problem standards, our problem is small and thus the DP algorithm will be utilized as it is easily coded in the desired web environment. In addition, the principal investigator has experience implementing and validating these algorithms.

Solving the example formulation that was presented earlier leads to the following solution (topics and number of contact hours): $x_A = x_B = x_C = x_D = x_E = x_F = 3$, $x_G = 2$, and $x_J = x_L = 1$. Thus it is suggested that the following topics, : (A) Interest Rates; (B) Benefit/Cost Ratios; (C) Present Worth; (D) Depreciation and Depletion; (E) Geometric Gradients and Spreadsheets; (F) Cash Flows; (G) Equivalence Relationships; (J) Rate of Return; and (L) Sensitivity Analysis be covered at their given durations to fill the 22 requested contact hours.

While the model will identify the desired topics and lengths, the final output provided to the user will be in the form of a syllabus, which requires topics, duration and a sequence. Thus, the knapsack solution will be sequenced (according to priority rules) and returned to the user. Other references directly related to the developed outline, such as textbook information and case studies will also be made available.

The primary reasons for proposing a knapsack model are that it fits the decision situation accurately and can generally be solved quickly. The example model presented in this proposal was solved in less than one second using LINDO[4], an optimization software package. It is expected that a "real" example would take on the average of 3-5 seconds to solve, which we feel is a reasonable solution time.

2.4 Model in Decision Making Framework

It is envisioned that the model will be implemented as a resource in a decision-making framework for Engineering Economy educators. Figure 1 illustrates this framework in that user specifications are input to the system, the model develops a course syllabus, and an iterative procedure follows until the user is satisfied.

This iterative procedure is required as people have varying opinions. One cannot expect a developed model to provide an acceptable course syllabus each time. Thus, we have included a feedback loop in which the user can request that the syllabus be altered. These changes may include reducing the time spent on a topic, eliminating a topic, or including a different topic (or topics). If feasible changes are requested, the model can be resolved. For example, if an instructor requests to eliminate topics in the core, the system will notify the educator that this is not feasible. Furthermore, if the user requests more topics than can be feasibly put into the knapsack (they force too many x_j variables to be positive), then the feasibility check alerts them and asks for a revision.

Again, consider the solution provided in the example problem. If the instructor insists that the Replacement and Retirement topic (Category H) be included, the solution could be altered through the feedback mechanism. From this request, the following constraint would be added to the system:

$x_H \geq 1$ (additional requirement)

Essentially, this acts as an additional core constraint. The solution to this revised problem recommends the removal of 3 contact hours of topic D (Depreciation and Depletion) while including two hours of Income Taxes (I) and one hour of Replacement and Retirement (H). Mathematically, the solution now is: $x_A = x_B = x_C = x_E = x_F = 3$, $x_G = x_I = 2$, and $x_H = x_J = x_L = 1$.

Note that if the educator had requested 17 hours of topics outside of the defined core, the problem would have returned an infeasible solution since there would not be enough hours to meet the core requirements. In this situation, the educator would be asked to revise their inputs.

This interaction with the user is complete when no more revisions are needed to the syllabus. The user would then have access to a database of information to aid in implementing the syllabus.

3. Extension of Model Use to other Engineering Courses

While it is believed that the model will have its greatest impact on the design and presentation of Engineering Economy courses, the model can also serve as a useful resource for educators desiring to incorporate engineering economy topics in other courses such as a capstone senior design course. In this situation, the educator could request topics to be included in a course syllabus with limited contact hours. To provide the necessary output, the "core constraints" would be turned off such that only the desired topics would be output. More important than the topics themselves, as the educators request the topics, the resources linked to these topics would be made available to the educator. The research of Thuesen and Sullivan[11] illustrated the benefits of incorporating economics into core engineering courses, including design. The model proposed in this paper would provide a helpful tool for educators interested in pursuing this approach.

The model can also be used to develop a follow-on engineering economy course as in the case of a two-part series. In this case, the educator could design the course for 60 hours (in other words, two 30-hour courses). In this way, much of the core requirements could be covered in the first course, with more advanced or elective material saved for the second course.

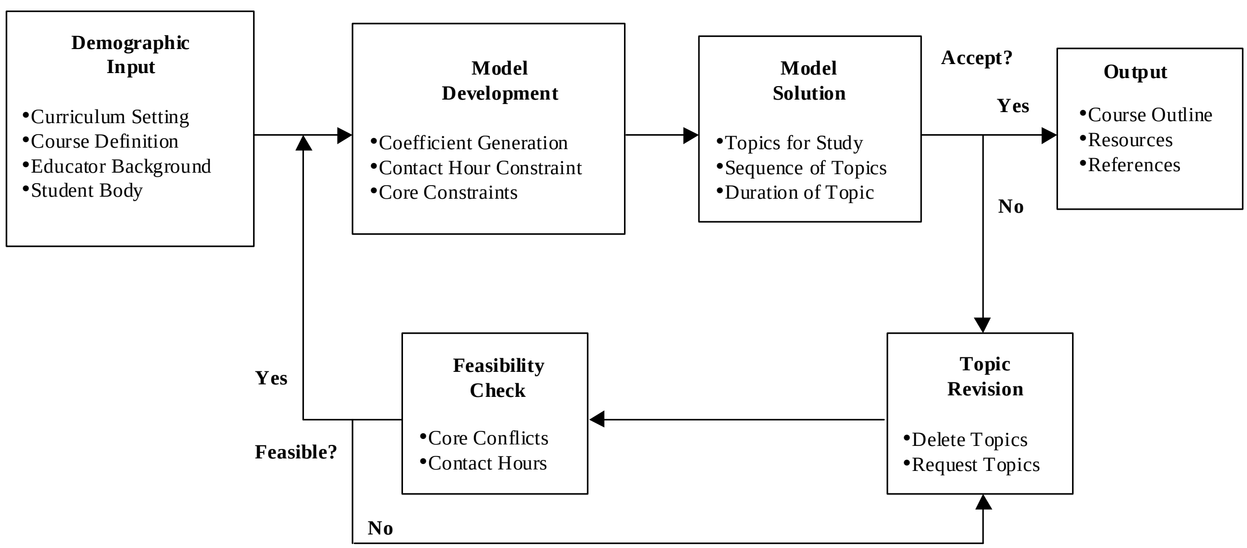

Figure 1. Proposed system for syllabus development.

4. Conclusions, Discussion and Future Research

We have proposed a knapsack model for helping an educator in the field of Engineering Economy develop a course syllabus. Obviously, no model can capture all of the intricacies of this decision. However, we believe that once fully developed and test, this can be a valuable resource for all educators, especially those new to the field.

There are some issues that must be further analyzed before a model of this nature can be integrated into a decision support system. The first issue is the objective function used in the knapsack model. The weights, which define the "value" of a topic in a syllabus, were derived from survey results. It is debatable as to whether this is the method of choice, as this assumes that current Engineering Economy teaching practices are ideal. This relates to the second issue of model inputs. Before this model can be built, the proper inputs to the model must be identified. This includes identifying all possible teaching environments, which is a formidable task. In addition, a comprehensive representative survey into the teaching of Engineering Economy must be conducted to ensure a representative database to develop the model for actual Engineering Economy educators. These are principal tasks currently being addressed by the research team.

Obviously, there is also room for improvement with the model itself. Currently, the model assumes that a second contact hour is equivalent to the first contact hour for a given subject. This may not always be true, as lecture topics often times follow the law of diminishing returns. That is, the "value" of teaching a second hour of a topic is not as high as teaching the first hour and the third hour is not as "valued" as the second hour, etc. To model this situation, a topic can be given a number of variables. For instance, topic A can be represented by A1 and A2, where the number represents the contact hours. Revisiting the example posed earlier, a possible new formulation would be:

$$
\begin{array}{lll}
\text{max} & 40x_{A1} + 39x_{A2} + 39x_{B1} + 38x_{B2} + 30x_{C1} + 29x_{C2} + \ldots + x_{Z2} & \text{(obj. function)} \\
\text{subject to:} & x_{A1} + 2x_{A2} + x_{B1} + 2x_{B2} + x_{C1} + 2x_{C2} + \ldots + x_{Z2} \leq 22 & \text{(contact hr constraint)} \\
& x_{A1} + x_{A2} \leq 1 & \text{(only select at most one topic A)} \\
& x_{B1} + x_{B2} \leq 1 & \text{(only select at most one topic B)} \\
& \ldots & \text{(only select at most one of any topic)} \\
& x_{Z1} \leq 1 & \text{(only select at most one topic Z)} \\
& x_{A1} + x_{A2} = 1 & \text{(core requirements for topic A)} \\
& x_{B1} + x_{B2} = 1 & \text{(core requirements for topic B)} \\
& \ldots & \text{(other core requirements)} \\
& x_{A1}, x_{A2}, x_{B1}, x_{B2} \ldots x_{Z2} = \{0,1\} & \text{(integer constraint)}
\end{array}
$$

Note that the formulation requires additional constraints such that a topic is placed in the knapsack only once. For example, the solution can only include Topic A1 or A2 (or neither if Topic A is not in the core), but not both. Also, each variable takes on a value of 0 or 1 (integer constraint) as the contact hours are defined by the variable. A value of zero means that the topic at the defined number of contact hours is not placed in the knapsack while a value of one means it is in the knapsack (and thus on the syllabus).

Despite the additional constraints, the objective function may now be more realistic as the diminishing returns are included. Determining which model to implement will be a function of the research and will become evident through examination of the survey results. Also, placing a value on the difference between teaching one or two hours of a subject will also be investigated (in this small example, the value was reduced by one point for each additional hour of instruction).

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