2006-1647: A METHOD TO EVALUATE RELATIVE INSTRUCTIONAL EFFICIENCIES OF DESIGN ACTIVITIES FOR PRODUCT PLATFORM PLANNING

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A Method to Evaluate Relative Instructional Efficiencies of Design Activities for Product Platform Planning

Abstract

Product Platform Planning is markedly different from the traditional product development process and a relatively new development in engineering design. Different than optimizing products independently, it requires integration of principles from both management and engineering design for developing a set of products that share common features, components, and/or modules. To present the basic principles of this new and different engineering design topic as well as current research on planning and architecting families of products, in our previous work, we developed an online resource, including, a set of three cases, a tutorial, and a glossary in a multimedia format hosted on the Internet. The cases are based on a family of product power tools. They present information in the form of function diagrams, assembly diagrams, customer needs and market-segment data. They have been designed to elucidate different product platform problems at increasing levels of complexity.

This paper presents a Data Envelopment Analysis (DEA) model to evaluate the relative instructional performance of the first two case studies. The model involves four engineering students' perceptions about the case assignments collected via survey methods. In the analysis, the instructional efficiencies of the case studies were defined in the form of a ratio of three carefully selected outputs (assignment appropriateness, clarity, and effectiveness) to a single input variable (assignment technical complexity). The DEA model has shown that Case 2 is almost twice as efficient as Case 1 with respect to the students' experience with the case assignments. Presenting the concepts of function-based family design, component sharing, and modularity along with customer needs-driven approaches and decision-making appeared to be instructionally more intuitive and cognitively more complete for the students.

A major outcome of this research is an improved understanding of relative instructional efficiencies of the learning activities for product platform planning. This supports choosing the type of "what if" questions to be addressed in such activity creations. Furthermore, it contributes in terms of developing a relative measurement of instructional efficiencies of design activities with the simultaneous considerations of their desired outputs and input variables. Therefore, the proposed evaluation method eliminates assigning weights to be attached to each input and output, as in the usual index number approaches.

1. Introduction

Product platforming provides product diversity through shared resources at a reduced price by sharing components, interfaces, knowledge, production processes, etc[1]. Products that are "derived" using components or modules from the platform constitute a product family. Product platform planning (or product family planning) calls for the simultaneous, planned development of a set of related products that share features, components, and/or modules[2].

Product platform planning is different from the conventional product development process in that it involves the planned design and development of a few different products at the same time. Being a currently developing methodology, it is rarely a part of the engineering curriculum. Considering its relevance in today's industry, it is important that it is incorporated in the education system. Platform planning involves management of design, and involves management concepts such as market research, customer needs, product management, etc. These concepts are new to an engineering student and have to be presented in a manner that allows for greater understanding and learning. On the other hand, a management student or product manager in industry may not be familiar with engineering fundamentals and will have to be given a suitable introduction.

As all this calls for the integration of platform planning into the engineering and business curriculum, we have developed an online learning tool in our previous work[3]. The tool enables problem-based learning through a set of three case studies based on a popular family of power tools. Specific activities guide learners through a platform planning process. In addition to product platforming, the cases promote learning concepts of function-based family design, component sharing, modularity, customer needs-driven approach, market analysis, decision-making, etc.

Five senior engineering students have studied these three case activities during their summer research experience at SMART (Systems Modeling and Realization Technologies) laboratory at Virginia Polytechnic Institute and State University[4]. The students were sponsored by the National Science Foundation's Research Experience for Undergraduate (REU) Program for product platform planning[5]. This study involved the students' learning experiences with the case studies. First, the students' perceptions about the case studies were collected using survey method. Then, a Data Envelopment Analysis (DEA) model, a linear programming-based performance evaluation methodology, was used for a relative efficiency evaluation of the case studies using this collected information.

Particularly, in this paper we demonstrate how DEA can be adopted as a relative instructional efficiency analysis tool. In this preliminary study, we found that DEA easily managed to account for differences in the selected input characteristic, case study technical complexity, which impacts the learning tool instructional performance and the suitability of making cross-case comparison. Therefore, this approach allowed an objective comparison of the case studies on a set of selected actual measures.

Section 2 presents examples from the literature in design concepts evaluation approaches. Additionally, the same section presents a brief review of relevant DEA literature and background information on the learning tool. Section 3 includes information about the survey method used to collect data for the DEA model. As the DEA model specifications are presented in Section 4, its results are discussed in Section 5. Finally, conclusions and future work are provided.

2. Literature review and background on the learning tool

This section presents a brief literature review as well as background information on the learning tool[3]. The literature review consists of information on the existing approaches for evaluating design concepts, the principles of designing the measurement experiments, and an introduction for Data Envelopment Analysis (DEA).

2.1 Design concept evaluation approaches and designing measurement experiments

A design concept generation approach was proposed by Linsey et al[6] as an evaluation to students' learning outcome. In particular, the effectiveness of functional modeling during conceptual design via its impact on student designer performance was investigated in their study. The study includes three outputs of a design activity: quantity of ideas, technical feasibility, and novelty.

On the other hand, Kenneth et al[7] used a survey method to measure student perceptions about their professional growth and correlated them with perceived course emphasis on learning outcomes for design skills, teamwork skills, and communication skills. Their evaluation involves students' performance in learning design conceptualization in a much general manner than the mentioned previous work. Their survey contains seven contracts: teamwork, information gathering, problem definition, idea generation, evaluation and decision making, implementation, and communication.

Another overall student designer learning assessment was proposed by Safoutin et al[8]. In their study, a design attribute framework for course planning and learning assessment was introduced. In this study, the intention is to transform the Accreditation Board of Engineering and Technology (ABET) learning outcomes into a standard and generalized assessment tool. The framework includes two dimensions of a given learning outcome: individual components of the outcome and nature of student understanding of each component. The individual components of the outcome are presented in terms of a set of design activities such as need recognition, problem definition, establish design objectives, etc. The nature of understanding of each design component is presented by using selected seven cognitive and affective categories of Bloom's taxonomy of educational objectives[9,10]. The selected categories are knowledge, comprehension, application, analysis, synthesis, evaluation, and valuation. Based on the framework, survey questions focusing on performance and how students approach design problem solving, rather than on recall of information can be developed.

Our learning tool calls for the delivery of both effective and efficient instructional service to its users. Therefore, measuring only effectiveness as the main focus of the abovementioned studies in the literature and disregarding efficiency may be an incomplete (yet still valid) approach to performance assessment. As Barnard states, an action is effective when it results in a specific desired end or the right thing. When the unsought consequences or secondary desires are attained, then the action is efficient[11]. Obviously, in an instructional adequacy concept, the actions of teaching and learning are desired to be effective, i.e. demonstration of desired learning behaviors such as good design outcomes. But it is also reasonable to assume that efficiency, i.e. appropriate material content, clarity in teaching material presentation, information accessibility, etc., possesses importance and thus needs to be measured. The studies briefly mentioned above and other related works have showed us that it is an appropriate initial step to assess the case studies' instructional efficiencies based on the users' perceptions. The literature was also found supportive about setting up a positive correlation between the students' perceptions and the relative instructional efficiencies of the case studies.

Meanwhile, designing a measurement experiment is as important as a performance measurement system. Although they are examples of effectiveness measurement approaches, the following literature for designing experiment for assessing idea generation for conceptual design have guided our effort on identifying efficiency measurement parameters and designing the experiment of this work. Shah et al[12] define two types of variables to design an experiment for conceptual design. The first type—experiment variables—is defined as the variables whose effect on idea generation needs to be studied explicitly during the experiment. The second type—nuisance variables—is variables that are not of specific interest to the experimenter but that can still influence idea generation. As an example, various characteristics of designers influence the idea generation process, such as personality, motivation levels, and mood, etc. The effect of these nuisance variables needs to be blocked or controlled during the experiment in order to observe the effect of the experiment variables.

Additionally, Shah et al[13] identify three classes of variables as being important for characterizing the method: design problem, human factors, and the environment. It is observed that most studies focusing on evaluating idea generation methods consider human and environment variables as nuisance variables. The method variables depend on the specific idea generation method and can be identified from the procedure of each idea generation method. Examples are group size, cycle time, number of iterations. Specific to the platform planning method, quantitative (numeric values) metrics of redesign complexity, assembly ease and value add metrics[14] can be determined a set of method variables. These variables are important since the efficiency of a platform idea generation could vary by changing these variables. In addition, the variables that characterize the nature of design problems need to be studied in the experiment. Widely used problem variables in the literature are complexity, degree of innovation needed, and decomposability. In terms of human factors, it is recommended to choose "equivalent" sets of designers in as many respects as possible, such as their backgrounds or technical skills. Lastly, environment variables such as time constraint (deadlines), the location, ambient temperature, lighting, seating, etc. need to be controlled by maintaining an equivalent or an identical combination for all the groups involved in an experiment.

Moreover, experiments on idea generation can be conducted in two ways[13]: directly and indirectly. For the former, the influence of method and design problem variables on the quantity, quality, novelty, and variety of ideas generated is observed through experiments. Although this information would be useful for selecting a specific idea generation method to solve a specific design problem or evaluating different solutions to the same problem using the same method, the experiments do not explain why these variables affect the outcome of idea generation. On the other hand, in the indirect method, the effectiveness of idea generation methods is predicted in terms of the components associated with the method. Thus, the components approach explains to a certain degree why an idea generation method is effective.

In sum, our work employs a direct method involving a set of experimental variables. Possible nuisance variables are assumed to be equivalent for all the student designers and not changing through out the experiment. For example, student designers' background, characteristics, capacity, and all the other environmental factors are assumed to be identical.

2.2 Data Envelopment Analysis

DEA is a mathematical method based on the principles of linear programming theory and application. It enables one to assess how efficiently a firm, organization, agency, or such other unit uses the resources available (inputs) to generate a set of outputs relative to other units in the data set[15,16]. Within the context of DEA, such units are called Decision Making Units (DMU). A DMU is said to be efficient if the ratio of its weighted outputs to its weighted inputs is larger than to the similar ratio for every other DMU in the sample[16]. The weights used are DMU-specific and during the application of DEA they are chosen by each DMU to maximize its own efficiency rating. The selection of the weights is only subject to limitations that they should be positive (or in certain instances non-negative) and they cannot result in an efficiency score larger than 100% or 1 in a zero to one scale[17, 18]. The weights for the inputs and outputs do not need to be identified by the researcher and instead they are determined by the DEA model in the best interest of DMUs[18]. The major advantage of DEA is that each input and output can be measured in its natural physical units. DEA can be performed to assess the relative efficiency of DMUs in a group within a single period or over a sequence of periods[19].

To be able to perform DEA, the researcher needs to choose homogeneous DMUs that use a variety of identical inputs to produce a variety of identical outputs. Calculated efficiencies are relative to the best performing DMU (or DMUs if there is more than one best performing DMU). The best performing DMU is given an efficiency score of 100 percent or 1, and the efficiencies of other DMUs vary, between 0 and 100 percent or 0 and 1, relative to this best performance[15]. However, it should be understood that DEA is a relative efficiency calculation tool as efficient frontier is not absolute but determined by the data set under investigation. For the accuracy of the model, it is important that variables that most impact the DMUs are included. However, if too many variables are included, a DEA model loses discriminatory power. That is, all or most units become efficient due to their unique levels of inputs and outputs. The recommended maximum number of input and output variables is equal to one-half the number of DMUs in any given category or analysis[20].

DEA has been widely applied to a multitude of problems in a variety of domains[21]. To the best of our knowledge, DEA has not been used as an evaluation tool either for student learning or instructional performance of a teaching tool. As this research is the first of its kind, other application areas related to this research have been explored. Particularly, DEA applications in diverse nonprofit settings, such as social services and education institutes, were investigated, since such organizations include model data in similar forms to this research's. Some examples are service quality with respect to service timeliness and appropriateness, and customer satisfaction[21-24]. Performance variables in those applications helped us identify the variables in this study as well as their implementation in DEA. Currently, several DEA software packages exist to allow managers and researchers to implement DEA models without directly solving a linear program for each DMU[25, 26]. For this work, the Microsoft Excel-based DEA Solver program developed by Cooper et al[21] was used.

2.3 Background on the learning tool

The entire learning tool was developed in our previous work to present the basic principles of product platform and family planning as well as current research on planning and architecting families of products[3]. The aim of the online learning tool is to educate users on platform planning using problem-based learning. In order for the cases to be effective, two things need to happen. One, users will have to gain the basic principles as well as some details on platform planning before they can solve the cases successfully. Second, the cases themselves will need to be based on the knowledge of platform planning gained from the diverse literature that is prevalent today, in addition to being unified and coherent. In order to achieve these twin goals, there was a need for a methodology to guide this effort. Therefore a methodology placing a greater emphasis on the earlier stages of platform planning compared to current literature was developed. This is because the reason behind platform planning is to offer customers the variety that they need while at the same time ensuring market success of the products sold. This can be achieved only when greater attention is paid to the customer and the competition. This methodology forms the direct basis for the tutorial section in the online learning tool. As our methodology is presented in a greater detail in our previous publications[3], it consists of three major phases. The first phase involves understanding the customer, the market and competitors, and the firms own products and platforms. The next phase engages planning details including strategy, products, features and specifications for the planned family. The last phase involves actually developing architecture, or deciding on specification of platform and variant elements.

The tool has been designed to provide users with easily accessible information. The content has been organized to allow for simple, uncomplicated reading to allow for maximum learning. Pictures, diagrams, explanations and helpful links have been placed wherever needed. The website has been given six major sections in the form of index tabs: Introduction, Tutorial, Design Concepts, Glossary, Case Studies and Links. Sections with more than one major topic of content have a sub-menu as shown on the left side panel in Figure 2.1. Sequential links in the form of arrows are located to the left and right of the heading of a given topic. The color scheme of the website has been chosen to be pleasing to the eye and at the same time be effective in directing the user’s attention to relevant areas. Arial was chosen as the font to allow for maximum readability. Links are highlighted in blue. Also, the selected topic on the left panel is highlighted in light-blue. The sub-menu allows for easy access to any part of a given section, as opposed to a strictly sequential access. The page width has been limited to approximately 800 pixels so as to be viewed correctly on most web-browsers. Also, care was taken that the page displayed correctly in different browsers. Names of the participating universities were listed as icons below the left panel. These icons are linked to the corresponding faculty’s website in their universities. The website was created using Macromedia DreamWeaver in HTML (Hyper Text Markup Language). Some information has been linked to the main website in the form of Adobe’s Portable Document Format (PDF). This allows for the presentation of data including graphs, tables and pictures to display as it was designed, irrespective of the browser used.

Figure 2.1: Case 1 in the learning tool

The Introduction section gives users an introduction to the field of platform planning, the online learning tool, and a link to a page giving details about the people behind the website. The Tutorial section expands on the Methodology introduced above by giving examples of some of the concepts. It functions as a resource to people using the case studies. As a standalone (used without the case studies), it functions as a source of knowledge about Platform Planning. Links from sections of the cases are directed to relevant portions of the Tutorial section. The Design Concepts section consists of topics not directly related to platform planning but are related to it, and would be helpful to users. Concepts explained are architecture, function based design, Pugh method and House of Quality. The Glossary section contains terms in two major topic areas: platform planning and function-based design. The terms in function-based design are further partitioned into flow definitions and function definitions. The Links section of the website has links to resources like platform planning efforts at participating universities and other universities, links to tutorial, etc.

For the case study section, three cases were developed. These cases are based on platform planning for a set of power tools. The first two are based on Black and Decker's cordless tools and the third based on a hypothetical firm, Essel tools. The cases have been designed to have an increasing level of complexity, from easy through to refined.

The first case deals with "bottom-up" design of a platform. Figure 2.1 shows a page in the first case. The function model and assembly model of a Black and Decker Versapack drill are presented to the user. The assembly diagram consists of component names which are linked to their corresponding pictures. This gives users an idea of size and shape. Background on the Versapack family of tools is provided. Also, helpful links are provided. Links to relevant sections of the tutorial are provided. Information and pictures about grinders are given. The student is asked to design a cordless grinder with shared components from the drill. Specifically, the user is first asked to draw a common function diagram from which common sub-functions can be selected. Based on this, and information provided in the Resource page, the user reasons which components can be shared. The Resource Page gives links to the function diagram and assembly diagram for the drill, an exploded diagram of a B&D grinder, drill and grinder photos, and an interactive listing of drill and grinder component assemblies. Clicking on drill (or grinder) assemblies opens up a list of drill assemblies. Clicking on any of the assemblies gives a listing of components. Clicking on any other assembly closes this assembly and opens the other.

Case 2 teaches the concept of a vertical scaling strategy using Black and Decker's circular saw. The user is first familiarized with circular saw usage and features with corresponding pictures, description, and an exploded view diagram. Architecture concepts are then explained. A market segmentation grid for B&D products, as well as the proposed saw, is presented. It provides a table giving specifications for the proposed new family of cordless saws. A function model of the existing saw is given. The user is then asked to develop modules for the platform as well as variant products. The choice of method (modularity matrix or heuristic) is left to the user. Links to relevant tutorial section will be provided. Again, the Resources page contains helpful information.

Case 3 portrays an ideal top-down approach to family planning. The user is exposed to customer needs and market based approach to product design and management. In addition, the user is expected to use his or her decision-making skills. The case is based on the grinder platform of a fictitious tool company. Detailed information on grinders has been presented in order to make users thoroughly familiar with the types, usage and parts of a grinder. An exploded view of a diagram is presented. Subsequently, the market presence of the tool maker (Essel tools) is presented on a market segmentation grid. Customer requirements data is presented in the form of a table of means and standard deviations corresponding to different market segments and performance levels. The assignment section asks users to study the competition by actually studying online websites like Amazon to get details on prices and features. The users then need to decide which segment the company will enter first. Product specifications are provided by the users who then identify modules and draw a power tower and a family map. Again, helpful links are provided in the Resources section.

3. The questionnaire design and response analysis

Five engineering students spent the first half of the REU program (one month) at Bucknell University and the second half (one month) at Virginia Tech. At Bucknell University, the students were introduced to some product platform and family concepts by dissecting different families of disposable cameras and refrigerators. As a small part of the program at Virginia Tech, the students were assigned to study the learning tool. Since the students have similar education background and have experienced very identical environment (e.g., REU program), they were expected to be quite similar in utilizing the product platform and family knowledge they have studied. This study assumes that potential differences in human learning and reinforces to learn (nuisance variables) do not cause significant differences in the students' performance with the case assignments[12]. It is assumed that the students are equally capable of learning and utilizing the tutorial material. Therefore, the differences in their perceptions are solely attributed to the way the learning tool is designed. Additionally, the analysis is based on only the students' perceptions related to immediate learning behavior (studying the case assignments). No efficiency factors for displaying the learned behaviors for different design problems outside the case studies' or presenting learned behaviors in different forms than submitted design solutions for the assignments are included in this study[27].

During their first week of the REU program at Virginia Tech, the students studied all the materials except the case studies in the tutorial at their own pace. Once they all became familiar with the tool and the materials, they were assigned one case study per week in the following three weeks. The students worked and turned in case assignment 1 and 2, individually. They worked on case assignment 3 as a team and turned in a single design solution for the assignment. The students studied two days on the first case assignment and three days on the second assignment. A week was allowed for the team for the last case study. Solutions to all the case assignments were submitted electronically. Since no time extension was requested, it is assumed that the designated time lengths were suitable for the students to complete the assignments. As part of the REU program and besides studying the learning tool, the students dissected a family of coffee maker and recorded the dissected product data for the design repository at the University of Missouri-Rolla (UMR)[28].

After completing each case assignment, the students were asked about their experience with the case study via an online questionnaire. For the first two cases, a web-link to the questionnaire was provided to them through e-mail. Since the last case study was assigned as a team work, evaluation of its efficiency was not included in this study. No questionnaire was prepared for this case study, instead, the students were asked to send one informal report about their experience as a team with this assignment. In this paper, only the instructional efficiencies of the first two case studies are included. Further information about the questionnaire for Case 1 and 2, and responses to them are presented in the following sections.

3.1 Questionnaire Design

A single questionnaire was prepared and used to collect the students' perceptions about the first two case studies. The captured data is subsequently used by the DEA model developed in the next sections. With respect to the questionnaire construction, commonly known survey design and planning principles (i.e. construct identification, composing questions, and creating item scales) were applied[29, 30]. However, due to limitations in time and the number of tool users, constructing a pilot testing of the survey instrument was not possible for this study to refine the questionnaire. Instead, a reliability analysis was conducted for each case study based the actual responses. In the questionnaire construction, the overall purpose was to build the final questionnaire with the respondents in mind, for their ease and highest comprehension[31]. Table 3.1 presents the questionnaire constructs.

The questionnaires target to obtain the users' perceptions about the two case studies on three major issues: assignment appropriateness, clarity, and technical effectiveness. The assignment appropriateness factor aims to reveal whether a case assignment truly asks the users to apply and demonstrate what they have studied throughout the learning tool. It focuses on the alignment between the case contents and the tutorial topics. The assignment clarity targets to find out how good the case studies are in communicating with the users. Besides technical and language correctness, it investigates whether the users come across any conceptual difficulty in identifying the solution approaches to the assignment. The assignment technical effectiveness construct focuses on information accessibility, helpfulness, and meeting the users' immediate learning expectations. Additionally, the questionnaire includes a separate section for the users to report any other issues have not been asked. In this section, the students are also asked to indicate how often they needed to use external resources and asked help from the graduate student. It is believed that answers to these questions serve as a simple double check mechanism in interpreting the users' responses to the three major constructs. For example, we expect to observe a high frequency in asking for the graduate student's help when the assignment clarity is graded low.

Table 3.1: Questionnaire constructs and definitions

Construct	Definition	Item	Scale
Assignment Appropriateness	Alignment between the case materials and the techniques and information included in the tutorial	Questions 1 & 2	Categorical (1=Very poor; 6=Excellent)
Assignment Clarity	Ease of identifying the solution approach, and technical information and language correctness and clarity	Questions 3,4,5, and 6	Categorical (1=Very poor; 6=Excellent)
Assignment Effectiveness	Helpfulness in providing resources, and effectiveness in meeting the user's learning expectation	Questions 7,8,9,10, and 11	Categorical (1=Very poor; 6=Excellent)
Qualitative Questions	Quality Related	Three questions in section B	Open Ended

With respect to selecting survey scale, there is a lot of discussion in the literature. Some researchers believe that even numbered scales better discriminate between satisfied and unsatisfied customers, positive and negative reactions or perceptions, because there is not a neutral option[32-34]. On the other hand, some studies show that respondents generally choose a positive response in the absence of a neutral midpoint option. All of our constructs have even number scales (six points) without a midpoint. It is believed that this scale guarantees a higher percentage of "Excellent" scores from respondents who otherwise, will tend to give a "Very good" score. At the same time, it provides an option of "Very good" for respondents who are satisfied but not "delighted", instead of rating "Good". In contrast, the major disadvantage of this scale is that for some respondents differentiating among 6 different ratings may be difficult. For example, some respondents might have difficulty to distinguish between a rating 2 and 3, or 4 and 5.

3.2 Analysis of Responses to Questionnaire

Only, four out of five students responded to the both questionnaires for a response rate of 80 %. Inter-consistency (Cronbach's alpha) for each factor of the questionnaire was computed to gain an idea about the reliability of the questionnaire for each case study. Cronbach's alpha is defined as the average of the correlation coefficient of each item grouped in the same factor. Generally, an alpha value of 0.70 or greater is an acceptable level of reliability (the consistency measurement)[35]. SPSS software (statistics program) was used to calculate the inter-consistency values[36].

Table 3.2 presents the reliability statistics for both cases. To strengthen the correlation of items pertaining to the same construct, suggested item deletions by SPSS were carried on. In Table 3.2, the computation shows significant increases in the internal consistencies of the constructs of assignment clarity and effectiveness, when the third and eighth questions are omitted for the first case study. Therefore, we decided not to include Question 3 and 8 in the further analysis of this case study. For the assignment appropriateness construct, no correlation factor can be calculated since the standard deviation for the responses to the second question happens to be zero in Case 1.

Table 3.2: Reliability statistics based on the responses for Case 1 & 2

	Construct	**Mean**	**Standard Deviation**	**Cronbach's Alpha**	**Cronbach's Alpha if Item Deleted**
Case Study 1	Assignment Appropriateness	5.13	0.6	N/A	**N/A**
	Assignment Clarity	4.58	1.08	0.75	**0.86 (Question 3)**
	Assignment Effectiveness	5.31	0.60	0.54	**0.86 (Question 8)**
Case Study 2	Assignment Appropriateness	4.75	0.71	**0.7**	N/A
	Assignment Clarity	4.94	1.00	**0.84**	0.83 (Question 3)
	Assignment Effectiveness	5.17	0.72	0.54	**0.75 (Question 8&9)**

For Case 2, Table 3.2 displays the suggested item deletions yielding improvements in the Cronbach's Alpha values. The reliability of the appropriateness is already higher than 0.7. This is also true for the assignment clarity construct. Therefore, all the items of these two constructs for the second case study are kept. For the assignment effectiveness construct, both Question 8 and 9 had to be dropped to improve the inter-consistency from 0.54 to 0.75.

Figure 3.1 displays the response distributions for the both case studies after the suggested items are excluded to obtain the acceptable Cronbach's alpha values in bold in Table 3.2. In Figure 3.1, the patterned distributions are for the constructs of the second case, as the clear boxes are for Case 1. For Case 1, the average responses to the items of the three constructs of the questionnaire stretch from second half of the score of "Fair" (3.7) to "Excellent" (6). For Case 2, this range stretches from score 4 "Good" to 5.8, second half of the rating between "Very Good" and "Excellent". There are no outliers. Based on the response distributions in Figure 3.1, the students graded the technical effectiveness of Case 1 higher than its other two constructs. This construct has not only the highest mean value among the three, but also a relatively narrower distribution at higher scores, between 4.7 (~Very Good) and 6 (Excellent). The students' responses for the appropriateness of Case 1 concentrate towards the upper half of the range from 4.5 (between Good and Very Good) to 5.5 (between Very Good and Excellent). The assignment clarity of Case 1 has the largest range from 3.7 (~Fair) to 5.3 (Very Good). Therefore, it has the lowest, but still positive (≥ 4.5), mean value among the three constructs. Based on these observations, it can be said that the assignment clarity of Case 1 had the most problematic issues for the students, as the assignment effectiveness was the most satisfactory. As an example of a design improvement, ease of identifying the problem solution approach for this case assignment can be investigated and improved. Similarly, the assignment effectiveness of Case 2 has received the highest average score with the shortest range within the constructs of this case. In contrast to the first case, the assignment clarity has the second highest average score while the assignment appropriateness has the lowest one. Base on these, it can be said that the students had difficulties in Case 2 relevant to the assignment appropriateness, while the assignment effectiveness of Case 2 was found to be the most satisfactory. For a design improvement, the alignment between the case materials and the techniques, and information correctness in the tutorial can be focused.

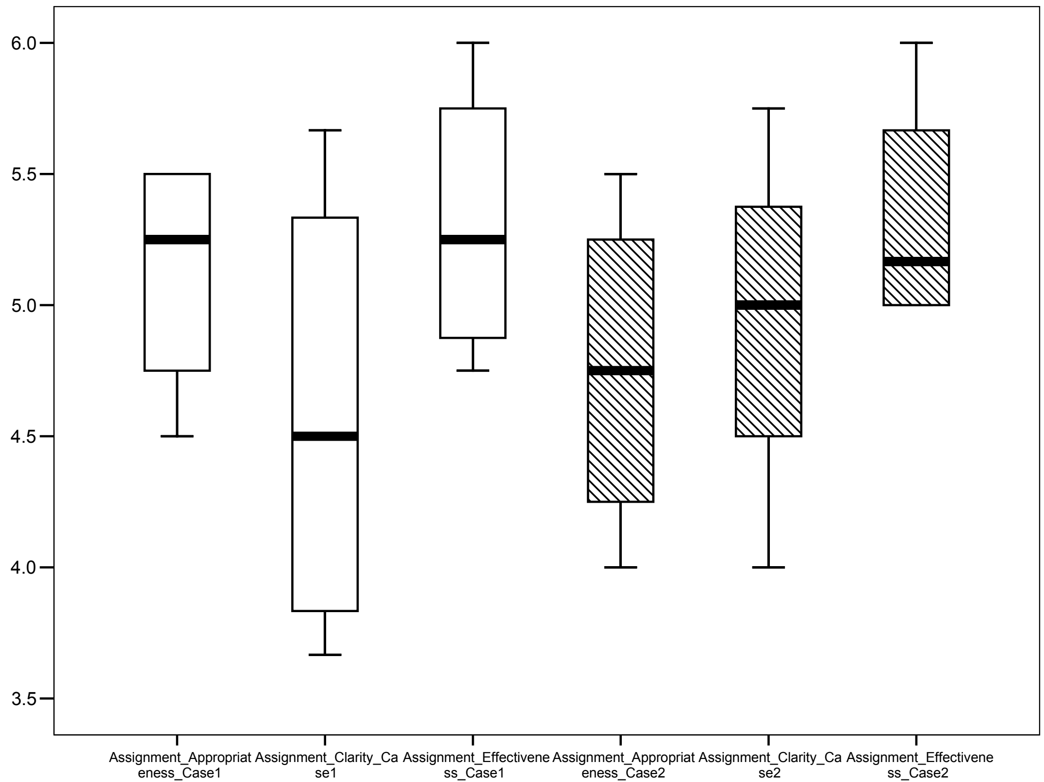

Figure 3.1: Response distributions for Case 1&2 after excluding the indicated items in Table 3.2

Although Figure 3.1 presents the differences in the students' perceptions about the three constructs in each case study, it can not present relative comparisons between the same constructs across the cases. Without including any information whether the presented ranges and average scores are actually acceptable for the content and the scope of the cases (i.e., high versus low assignment complexity), such comparisons are not fair. Therefore, it is not right to refer a construct of Case 2, say assignment appropriateness, to the same construct of Case 2 or vice-versa for a design improvement, when the differences between the cases are not included in the analysis. As this issue is addressed in the next sections, DEA provides us a means for comparing the instructional efficiencies of the cases objectively.

This section has discussed the students' perceptions about the cases studies through studying the case assignments. This information helped us identify the variables and their values for our efficiency analysis. Next section provides detail information about the process of the variable selection for this analysis and the development of the DEA model.

4. DEA Model Specification

We made the decision to build the model by utilizing the results from the abovementioned questionnaires. Although this helps conducting a preliminary evaluation of relative instructional efficiency of the two case studies, the data set employed does not capture all potential case assignment characteristics (input variables) that could impact students' perceptions about the case studies or other performance outcomes (such as displaying the knowledge in other design activities). In addition, a more comprehensive efficiency assessment requires application of subjective and objective usability tests including more than four tool users with different background. As a result, the presented model and its results are limited in many ways. Therefore, one more time, we want to underline that this work is intended to be an initiative for a DEA application in evaluating relative instructional efficiency of the online tool in a quantitative manner. We believe such an application is the first of its kind in this field. Further, we believe that this approach provides a very informative and practical way of efficiency measurement for similar applications with both complex and simple problem setups.

The first step in modeling instructional performance of the case studies using DEA was to identify actual input and output variables of interest. Figure 4.1 shows the selected variables for the model. Although one might think student design outcome score as an obvious output variable, it is excluded from the actual model to stay consistent with the real intention of this work: evaluation of the instructional efficiency of the case studies. As mentioned in the literature review section, design outcome scores of students are commonly accepted as one of the indications of the effectiveness of student learning. Such information is more appropriate for a DEA model intending to evaluate student efficiency in learning the material with respect to some relative set variables such as time constraint or nuisance variables such as motivation level. Therefore, although the students' design outcomes for both cases have already been scored, they were decided to be included to observe the effectiveness of the case studies in future work, but not for evaluating the case study efficiencies.

As mentioned before, the students' performance in learning the tutorial material is assumed to be identical in this research. Therefore, the efficiency of the learning tool should be measured in terms of the differences between our intended education objectives integrated in the case studies (assignment technical complexity) and the students' experience with the assignments. Therefore, as presented in Figure 4.1, assignment technical complexity is defined as the only input. Students' perceptions about the case studies in terms of their clarity, appropriateness, and effectiveness are defined as the outputs. The assignment technical complexity is determined according to the concepts (teaching objectives) included in the case studies presented in Section 2. During the design of the tutorial, the complexity of Case 1 was intended to be lower than Case 2's. This was achieved with integrating relatively less comprehensive product family development assignment in the first case study. A brief reminder of the contents of the cases, Case 1 involves product family architecture from the functional and component perspectives.

Case 2 includes market segment needs in product family architecture. However, in the actual DEA model, the numerical value of the technical complexity has to be entered in a positive correlation with the outputs (see the DEA literature review section). Therefore, in the actual model, the complexity indices of the first and the second case study are entered as 2 and 1, respectively. Finally, a decision-making unit (DMU) is defined as a single problem solving instance in the model. Since two problem solving instances from each (four) student can be used for this analysis, the total number of DMUs in the model becomes eight. Defining problem-solving instances as DMUs provides us the flexibility in conducting analyses from different perspectives such as from the case study and student perspectives as presented later. Additionally, having eight DMUs with four variables in Figure 4.1 is an appropriate combination in terms of the discrimination power of DEA (see section 2).

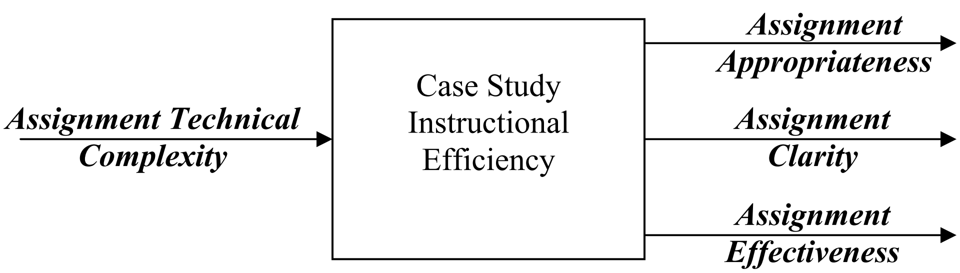

Figure 4.1: DEA Model input and output variables

The CCR (initially proposed by Charnes, Cooper and Rhodes in 1978) model was used for the efficiency analysis. Our major intention in the design of the tutorial is to have the case studies clear, appropriate and technically effective as much as possible. Therefore, an output oriented approach, CCR-O, was selected. Consequently, our linear programming model attempts to maximize outputs (clarity, appropriateness, and effectiveness) without requiring more of any of the observed input variables (technical complexity level).

Also, the selected model, CCR-O, assumes the constant returns to scale of activities. That is, if an activity (x, y) is feasible, then, for every positive scalar t, the activity (tx, ty) is also feasible. The general CCR linear programming formulation used for this model is presented as follows:

Max θ

Subject to

$$\sum_{j=1}^{N} \lambda_j y_{js} \geq \theta y_{j_o s} \quad \forall \text{ s} = 1 \text{ to m}$$

$$\sum_{j=1}^{N} \lambda_j x_{jr} \leq x_{j_o s} \quad \forall \text{ r} = 1 \text{ to n}$$

$$\theta \geq 0, \lambda \geq 0$$

where:
j:- 1……N represents DMUs from 1 to N (8 for our case) with ‘j’ being any DMU,
jo represents a specific DMU,
x_{jr} is input “r” for “jth” DMU,
y_{js} is output “s” for “jth” DMU,
θ is efficiency score, and
λ is intensity or contribution.

The next section presents the model results and our findings to improve the tutorial design based on these results.

5. DEA Model Results

Table 5.1 presents the actual model data as well as DEA results from the developed CCR-O model. Given the model data, one might tempt to draw a statistical regression line fitted to them. A regression line, as normally determined in statistics, goes through the “middle” of these data points and so the points above it can be defined as excellent and the points below it are defined as inferior or unsatisfactory. One can measure the degree of excellence (or inferiority) of these data points by magnitude of the deviation from the thus fitted line. On the other hand, the frontier line designates the performances of the best DMUs and measures the efficiency of other DMUs by deviations from them. There thus exists a fundamental difference between statistical approaches via regression analysis and DEA. DEA identifies points on the frontier line for future examination or to serve as “benchmarks” to use when seeking improvement. The statistical approach, on the other hand, averages these points along with the other observations as a basis for suggesting where improvements might be sought[21]. This approach was actually demonstrated in the previous section where the responses to the questionnaires were analyzed based on Figure 3.1.

Table 5.1: CCR-O model results for identified 8 DMUs (case assignment solving instances)

DMU	**DEA Efficiency Score**	**Peer**	**Technical Complexity (Input)**		**Assignment Appropriateness (Output)**		**Assignment Clarity (Output)**		**Assignment Effectiveness (Output)**	
			Actual	CCR-O Projection	Actual	CCR-O Projection	Actual	CCR-O Projection	Actual	CCR-O Projection
1	0.48	6&8	2	2	5.0	10.41	3.7	10.61	4.75	9.89
2	0.54	6,7&8	2	2	5.5	10.12	5.7	10.42	5.5	10.12
3	0.52	7&8	2	2	4.5	8.21	4.0	10	6.0	10.95
4	0.51	6&8	2	2	5.5	10.58	5.0	10.88	5	9.62
5	0.90	6&8	1	1	4.5	5.1	4.0	5.15	4.7	5.2
6	**1**	-	1	1	5.5	5.5	5.75	5.75	4.7	4.7
7	**1**	-	1	1	4.0	4.0	5.0	5.0	6.0	6.0
8	**1**	-	1	1	5.0	5.0	5.0	5.0	5.3	5.3

In Table 5.1, the data is presented by the case studies. First four highlighted DMUs belong to problem-solving instances of Case 1, as the last four are for Case 2. DMU 6, 7, and 8 were found to be efficient by our model. As shown in Table 5.1, all the efficient instances are for the second case assignment. In other words, except the first student, all the students' second case study problem-solving instances are found to be efficient. Student 1 happens to have both the most and the least inefficient problem-solving instances (DMU 1 & 5) within the five inefficient DMUs. Inefficiencies of the other DMUs (2, 3, and 4), first case study problem-solving instances of Student 2, 3, and 4, are computed as very similar due to their identical input and similar outputs.

There is no slack in the input side (all the CCR-O projections are identical with the actual input data). Therefore the model maximizes the outputs for the given fact that there are two cases at two different technical complexity levels. However, some output CCR-O projections are found to be higher than the highest possible survey scale, 6 (Excellent). The reason why this case has occurred is that the constraints associated with the survey scale (1 (very poor) as a lower bound and 6 (excellent) as a higher bound) are not included in the model. To obtain the projection values between the boundaries, one might want to modify some other existing models proposed for incontrollable variable cases in the literature, such as bounded variable model[37] or categorical models[38, 39], for this output oriented approach with controllable variables and the constant returns to scale assumption. However, such a modified model will provide the same efficient and inefficient DMUs and the peer relationships[21]. In our case, the values under CCR-O projection in Table 5.1 provide information on where added outputs are needed. As this is the desired outcome of this initiative study, it sufficiently provides us a relative evaluation of the two case studies and insights on opportunities for design improvements. For more complex efficiency problems with more than two case studies, decision makers would gain more from modified models.

In our analysis, Case 1 does not have any efficient DMUs while the percentage of efficient DMUs within the second case is 75%. Also, the average efficiency score of the DMUs within Case 1 is 0.52 as Case 2 has an average of 0.97 efficiency score. As discussed above, all the peers of the problem-solving instances of Case 1 are within the second case study. Given these, Case 2 is dominantly, almost twice, more efficient than Case 1 instructionally. Correlating this result with the contents of the case studies, it can be said that the concepts of function-based family design, component sharing, and modularity were found instructionally more efficient when they were presented along with customer needs-driven approaches and decision-making. In other words, these topics all together appeared to be more intuitive and cognitively more complete to the students. The DEA model suggests improvements in all the outputs of Case 1. Therefore, the assignment appropriateness, clarity and effectiveness of Case 2 should be studied more closely to improve the same elements in Case study 1. Since the DEA model has included the differences in the inputs of the DMUs, these design improvement references are now based on a fair comparison.

Additionally, Table 5.1 presents an interesting case for DMU 5. The model benchmarks two efficient Case 2 instances, DMU 6&8, for its only inefficient problem-solving instance, DMU 5. In this case, the inefficiency of DMU 5 can be attributed to the student, Student1, who processed it, not how the case study is structured. Following on the same approach, next the DEA results are interpreted by student body (not students' efficiency in learning as it has been excluded from the very beginning). As the decision makers for improving the tutorial design, we gain more about how Student 1 has actually interacted with the case study, if we compare his interaction processes with the ways of Student 2 and 3. This will help us understand better why Student 1 has scored the appropriateness, clarity and effectiveness of the case studies the way he did. The model also benchmarks Student 2, 3 and 4 to himself. This urges us to pay attention the differences in these students' interactions with the two case studies to understand why the two case studies worked differently for the same students. For example, say Student 2 has needed external sources in the first case study more frequently than he did for the second case study. Finding this out, we will know better why Student 2 has scored the first case study lower for the effectiveness output. Furthermore, Table 5.1 suggests us to investigate how differently Student 2, 3, and 4 interacted with the first case study more closely for future design improvements.

6. Conclusions and Future Research

Providing a quantitative method for evaluating the instructional efficiency of our previously developed online tool for introducing product platform and family planning concepts, this study achieved its objective. Particularly, it helped us gain improved understanding of the relative appropriateness, clarity, and effectiveness of the two design activities for product platform planning. Future improvements in the design of these activities were also identified using generated peer relationships by the DEA model. The work has contributed in terms of developing a relative measurement of instructional efficiency of design activities with the simultaneous considerations of their anticipated outputs and input variables. In other words, the proposed evaluation method eliminated assigning weights to be attached to each input and output, as in the usual index number approaches.

In this study, DEA was used to analyze the instructional efficiency of the learning tool. Developing the CCR-O model, an output oriented model that assumed constant returns to scale, relative efficiency of the two case studies were evaluated. In the model, a single decision-making unit (DMU) was defined as a single problem-solving instance by a student. Additionally, case study assignment difficulty was chosen as the single input while assignment appropriateness, clarity, and effectiveness were determined as the three outputs. The output values were obtained by conducting questionnaires focusing on the students' perceptions about the two case assignments.

The model showed that Case 2 is almost twice as efficient as Case 1 based on the students' experiences with their case assignments. In other words, the teaching objectives included in Case 2 are presented instructionally in a more complete way. The model suggests improvements in all three outputs of Case 1 at similar amounts. Additionally, these design improvements are referred to how Case 2 is structured. The model results were also interpreted by a student body. Such an analysis revealed clues about where to look at or what to compare to gain a better understanding of the reasons behind the students' perceptions. Overall, as discussed throughout the paper, our model helped us identifying the sources and amounts of inefficiency for the two case studies.

However, it should be kept in mind that this is a preliminary study in which the process of identifying the characteristics of the production frontiers (i.e., constant or variable returns to scale) and the variables requires more work. Therefore, for future work, different DEA models and methods need to be developed to compare results. Additionally, expert knowledge on the problem needs should be utilized in a systematic way before arriving at a definitive conclusion. Comprehensiveness of selected inputs and outputs and the assumptions of the analysis should be scoped carefully. Also, input and output data should be collected from a larger sample size to increase the statistic reliability of the experiment.

Acknowledgement

This work was funded by the National Science Foundation through Grant Nos. IIS-0325402, IIS-0325321, NSF IIS-0325279 and IIS-0325415. Any opinions, findings, and conclusions or recommendations presented in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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