

# An Approach for Engineering Curriculum Integration in Capstone Design Courses\*

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*The current emphasis in design education is to integrate the engineering design function with all relevant engineering (as well as non-engineering) disciplines. This paper presents an approach to foster engineering curriculum integration both within a specific engineering field and between engineering fields. First, the nature of integrated design will be discussed. Then a curriculum integration approach will be presented and illustrated, followed by two other supporting integration techniques that can be used in the classroom to help engineering students wrestle with the synthesis of their undergraduate engineering education.*

## INTRODUCTION

IT IS NOT HARD to find the current emphasis on integrated design in engineering education and practice. Papers, books, videos, and conference sessions that address design integration are everywhere. When attending industry-lead seminars profiling the skill set required by future engineers a common theme emerges: a need for a broad-based individual that is capable of working in an integrated fashion in a team environment. Clearly, it is important to respond to this need, however, within the educational tradition this is easier said than done. This paper addresses one aspect related to the difficulty associated with integrating engineering design education: what approaches can be used to pull together a decomposed topic-based curriculum into a set of integrated design tools.

This integration problem is significant in that students are typically taught a wide range of courses (basic science, engineering science, engineering discipline specific, humanities), but little is done to provide any synthesis between the courses. There is rarely a discussion or exercise on how all of the topics interrelate. The capstone design course is most likely the last time a student will have the opportunity to think about the broad range of interactions between subjects and problem areas. Once they are on the job they will be required to solve problems under significant time pressure and will not have the luxury of contemplating how all of their education can be brought to play on a given problem. Therefore, the capstone design course is the ideal opportunity to ponder all angles of a problem, while all of the different topic areas are fresh. This is not to infer that course integration can not be addressed earlier in the engineering curriculum—to the degree that it

can it should—but the capstone course is the logical time for total curriculum synthesis.

This paper will first explore the topic of integrated design, then it will present and illustrate the proposed design integration approach for a capstone design course.

## BACKGROUND ON ENGINEERING DESIGN INTEGRATION

Design has been defined in a multitude of ways. Webster's definition of design is: 'to conceive and plan out in the mind; to devise for a specific function or end; to make a drawing, pattern, or sketch of; to create, fashion, execute, or construct according to plan.' This definition captures many aspects of design. What is missing from this definition of design is the interaction between issues in the design process. By the very nature of design a systems perspective is required. Considering the range of components that comprise a manufacturing system, in Fig. 1 some of the interactions that must be addressed if the final design is to achieve overall system objectives are illustrated. There are also a wide variety of design interactions that must be addressed within each component of the manufacturing system. For instance, at the product level there is another level of integration that must occur between the mechanical, electrical, chemical, etc. systems. In the light of an expanding system design perspective, Morely and Pugh [1, 2] have stated that the scope of integration should be expanded so that it ensures a design is totally consistent with the overall organization's objectives. They have proposed that it is necessary to consider all factors of the organization within the product design task. In what they call the 'business design activity model' the viewpoints of research, purchasing, marketing, development, manufacture, finance and sales are all considered as part

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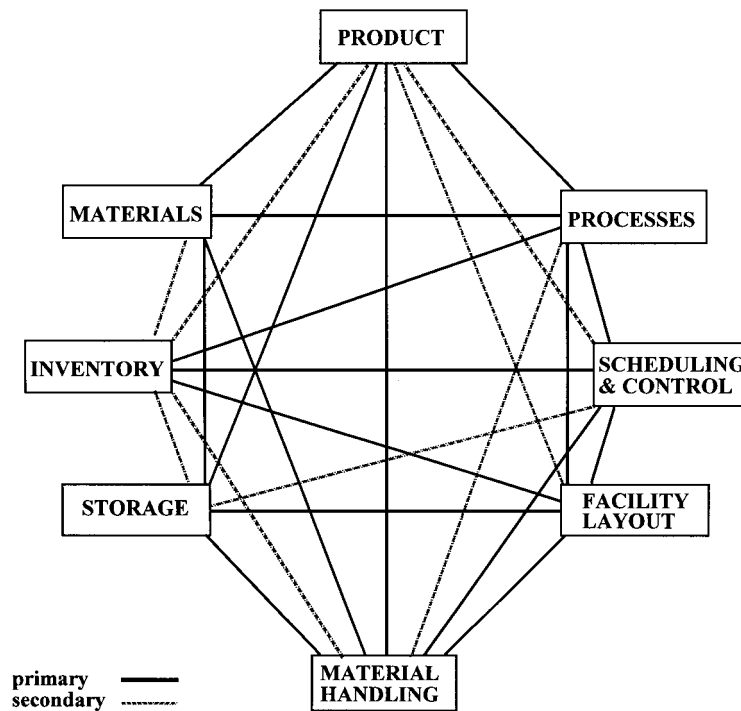


Fig. 1. Interactions between manufacturing system components.

of the product design process. Their premise can be summed up by their statement that, 'What is needed above all else in the context of design is the use of systematic methods which provide a structure so that disagreements converge productivity onto solutions all can understand and can accept' [1, pp. 219–220].

Based on the above, the concept that drives integrated design is to consider all factors concurrently during the design, so as to reduce the need to conduct post-design analysis. Thus, all customer, supplier, organizational (management, design, and production) issues are considered concurrently in an integrated design approach so that the design process focuses on meeting customer requirements as they are translated into engineering design criteria (constraints). The challenge facing engineering educators is to provide an education that gives students the tools to analyze integrated problems in a systems context that emphasizes optimizing the system rather than the component, with respect to the engineering design knowledge and techniques they have learned.

### TEACHING ENGINEERING DESIGN INTEGRATION

There are several issues that must be addressed when considering teaching integrated design. First, there is the issue of topic breadth versus depth. Second, there is the issue of design methodology. Third, there is the issue of design context. The following will briefly address the first two issues, then the rest of the paper will focus on an approach to providing design context so as to

provide an experience that integrates an engineering curriculum.

With the increasing body of knowledge in each engineering discipline and the perception that it is necessary to cover it all in a four-year program, it has been observed that there has been a decline or at least a lack of emphasis on synthesis/integration and creativity [3]. This raises a philosophical question, 'what responsibility do engineering educators have in teaching state-of-the-art knowledge versus problem-solving ability?' Is it sufficient to just to teach the techniques and knowledge-base and let experience provide the motivation for integrating them? Or, is it necessary to take responsibility for integrating engineering education at the possible expense of breadth? Without a doubt a basic level of knowledge is required, but at the present rate of knowledge expansion it is virtually impossible to cover all related knowledge. As a result it becomes more important that students be able to use what they know properly (from an integrated perspective) and be able to address real problems, versus, knowing all there is about a single topic.

Over the past 20 years there has been a concentrated effort to formalize a design process. This work has ranged from Hubka [4] who provides a systematic design process, to Suh [5] who sought to develop a science of design, to Rouse [6] who addresses the cognitive side of design. All of this research has provided new insights into the design process that need to be taught to engineering students.

Therefore, having determined the scope of an engineering education and incorporated current design methodologies, the need is for tools that provide a context for integrating the range of

courses taken by an engineering student. In the following sections, an approach is given for integrating an engineering curriculum that provides context with respect to problem-specific design objectives and decisions. This is followed by several supporting techniques that can be used in the classroom to support a design approach from a systems perspective.

#### *Capstone design courses*

Most engineering curricula have some type of capstone design course. These courses range from those which focus on solving a hypothetical case study, to having past industrial problems for students to solve without knowing previous solutions, to working on an actual industrial problem with an industrial sponsor. The following will describe the engineering curriculum in which the approach for curriculum integration presented in this paper was developed.

At the University of Missouri-Columbia the Industrial Engineering Capstone Design course used to be a single four-semester-hour course that focused on an industry-based problem (where students solved an actual industrial problem in context, and had multiple interactions with the company). Based on experience with this format it became apparent that this time frame didn't allow for exploring a wide range of alternatives or problem situations. Therefore, the Capstone Design course was separated into 2 semesters of 2 hours per course. This allowed for the first semester to concentrate on how to integrate all of the material that they had learned in their undergraduate studies, to learn how to think about problems from a more integrated perspective, to explore a case study from an integrated perspective, and to have an initial introduction to a real-life industrial problem that they would be working on in the second semester. The second semester then consists of the actual solution of the real-life industrial problem, with the expectation that their solution will provide value to the industrial partner.

The Capstone Design course had as its objective to integrate the following undergraduate courses:

- *General education*: Exposition and Argumentation, History, Humanities/Social Science, Economics, Mathematics, Basic Science and Engineering Science: Analytical Geometry, Calculus I, II, III, Differential Equations, Chemistry I, Physics I, II, Computer Programming, Engineering Graphics, Statics and Dynamics, Strength of Materials, Thermodynamics, Circuit Theory, Probabilistic Models;
- *Discipline-specific courses (Industrial Engineering)*: Evaluation of Engineering Data, Engineering Economy, Manufacturing Processes, Performance Measurement and Ergonomics, Deterministic Operations Research Models, Stochastic Operations Research Models, Applied Robotics, Systems Simulation, Quality Control,

Plant Layout and Material Handling, Integrated Production Systems, Management Information System Design, Scheduling Systems, and Industrial Process and Distribution Control Systems.

The above provides the context from which the curriculum integration approach was developed. However, regardless of the type of problem used as the basis of the capstone design course or the type of courses that must be synthesized, the following approach will assist students in obtaining a systems overall view of their education.

#### *Integrating an engineering curriculum: a QFD-based approach*

The modeling of the interaction between different engineering courses and design objectives that are relevant for a given design problem is addressed by applying the tool termed the house of quality [7] or quality function deployment (QFD) [8]. Although this tool has been primarily used as a tool to enhance product quality, its structure allows for any design objectives and body of knowledge to be integrated so that relationships between them can be analyzed.

QFD originated in 1972 at Mitsubishi's Kobe shipyard. Since then it has been used by both Japanese and US manufacturers successfully in their quality programs. The goal of QFD is to focus and co-ordinate skills within an organization and give a 'conceptual map that provides the means for interfunctional planning and communications' [7, p.63]. As such it is a very good tool for communication during the design process for both the negotiation of constraints and focusing on integrated solutions.

The general procedure for using QFD for integrated design is as follows. Figure 2 illustrates how the objectives and decisions are integrated to analyze their relationships.

1. Determine the overall design objectives in basic terminology (left side of Fig. 2). Objectives are first given as primary (overall) objectives of the design, and then are decomposed into secondary objectives which support the primary objectives.
2. Weight the secondary design objectives, since not all contribute to the overall objectives equally. A variety of multi-attribute weighting methods are available for this purpose.
3. Determine the primary and secondary (supporting) engineering design tools/topics that influence the design objectives (upper middle of Fig. 2).
4. Determine whether there exists a significant relationship between design objectives and engineering design tools/topics (middle of Fig. 2). Determine the objective measures for each engineering design decision (lower middle of Fig. 2).
5. Determine if there exists a significant relationships between engineering design tools/topics (top of Fig. 2)

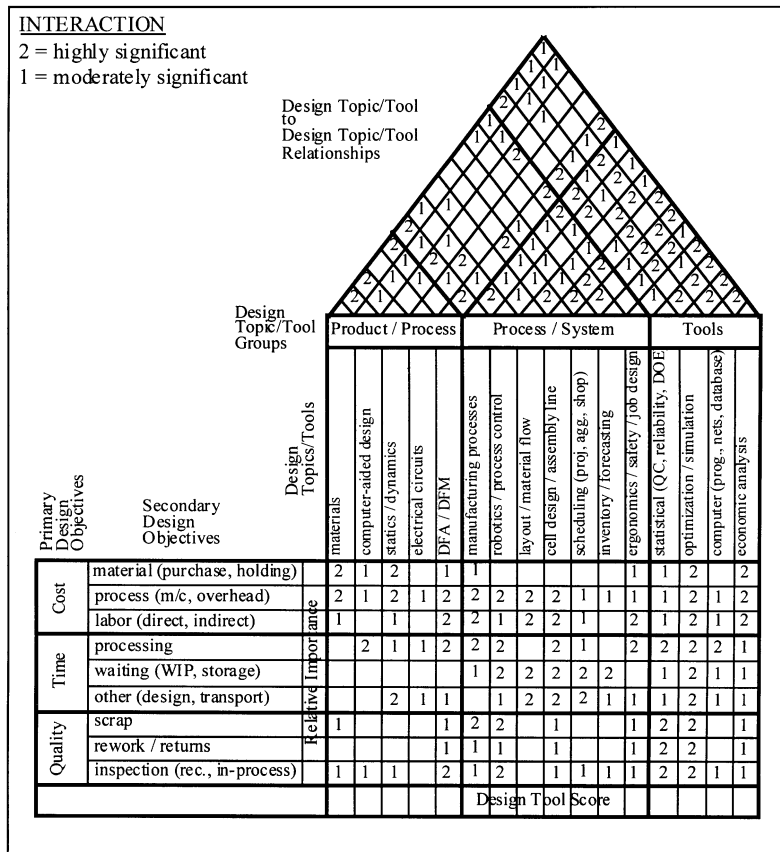


Fig. 2. QFD chart for general relationships between design objectives and design topics/tools for industrial engineers.

6. Determine if further decomposition of the design problem is needed. If so, the engineering design tools/topics from the overall diagram (how) can become the design objectives (what) for more detailed integrated design analysis.

The QFD approach forces designers to consider the interactions between different design decisions and maintains an overall objective perspective. If QFD is properly applied within design problems/projects it would ensure that students do not overlook any significant engineering design tools that could influence overall design objectives. It would also alert students to the most profitable aspects of the design on which to focus their creative efforts. The following will illustrate how a QFD-based approach can be used to foster engineering curriculum integration.

*Illustration of QFD applied to engineering curriculum integration*

The QFD diagramming technique is first introduced to the students by developing a list of all design objectives and design tools that are related to their engineering discipline. This is an iterative process as there will be a need to do some aggregation of both the objectives and tools. Figure 2 is one example of an overall discipline diagram that was generated by industrial engineering students. After the overall QFD diagram is developed the

students develop a QFD diagram that represents the capstone design project from an educational perspective, not an execution perspective. Figure 3 is an example of such a QFD diagram that illustrates that there are two major sets of objectives and there is a set of activities that they must pursue if they are to successfully fulfill the project objectives. After having completed these two objectives, the teams are ready to begin the process of creating QFD diagrams to assist them in executing their capstone design projects.

Figures 4 and 5 are examples of how project teams have used a QFD diagram to analyze the interactions between the project objectives and design tools/topics that they have learned over the course of their education. In both cases the design objectives and each objective's relative importance have been obtained from the project's industrial sponsor. Based on this, the teams select what they consider to be the most appropriate set of design tools/topics to address the objectives, then they explored the interactions between objectives and tools/topics using a simple weighting scheme and the interactions between design tools. The relationships between design objective and tools/topics are derived based on what they have learned in each individual course concerning the scope of the application of the design tool/topic. For example, in Fig. 4 the set of design tools/topics related to cell design impact the design objectives

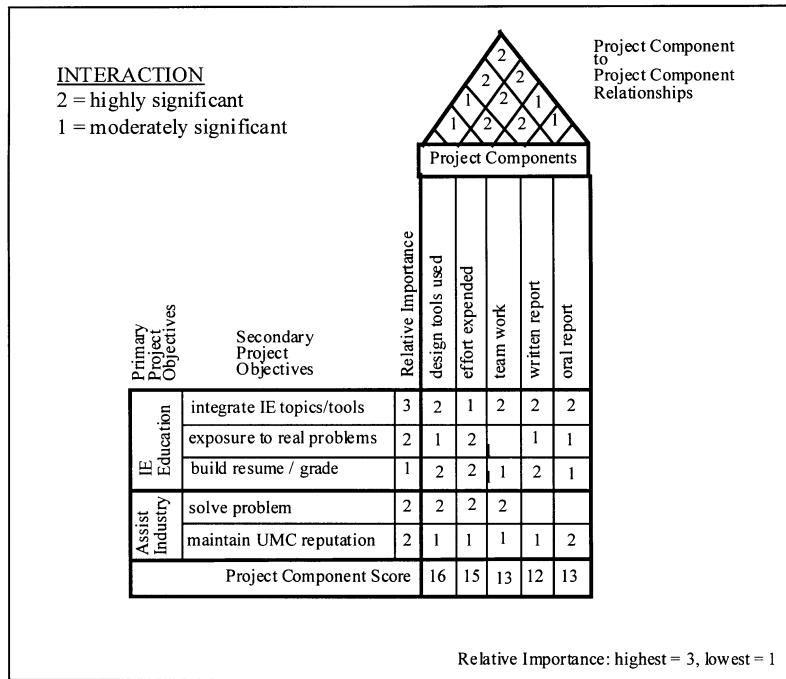


Fig. 3. QFD chart for overall capstone design project.

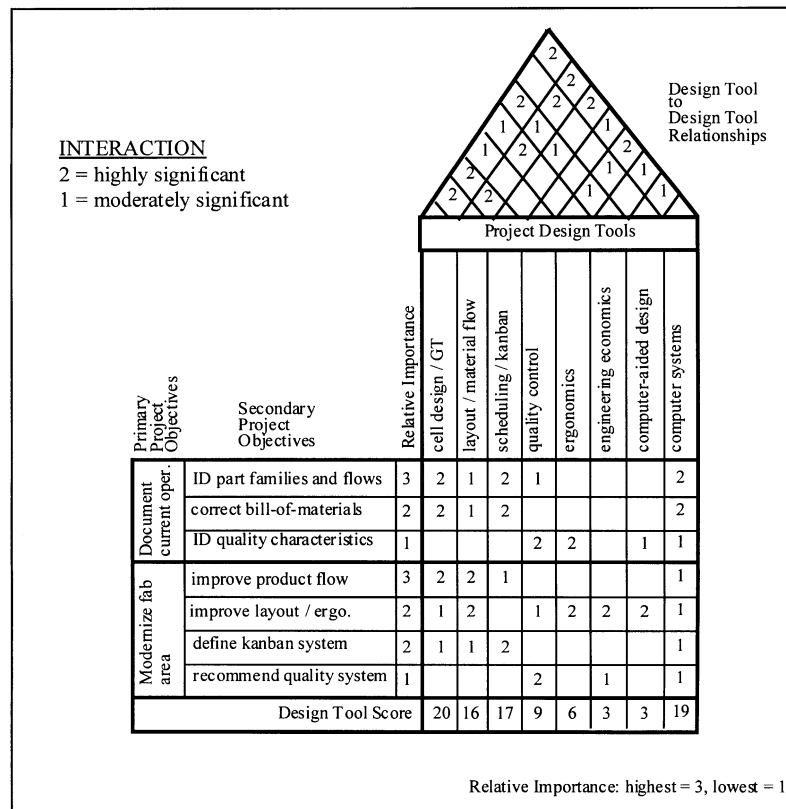


Fig. 4. QFD chart for specific capstone design project #1.

of part family identification, bill-of-material accuracy, and product flow in a very significant manner. The design objectives related to layout and ergonomics and kanban system are impacted to a lesser degree. The relationships between the

various design tools requires careful consideration as they have not typically been taught to think of these relationships. For example, in Fig. 4 the design tools associated with cell design interact with almost all of the other design tools to some

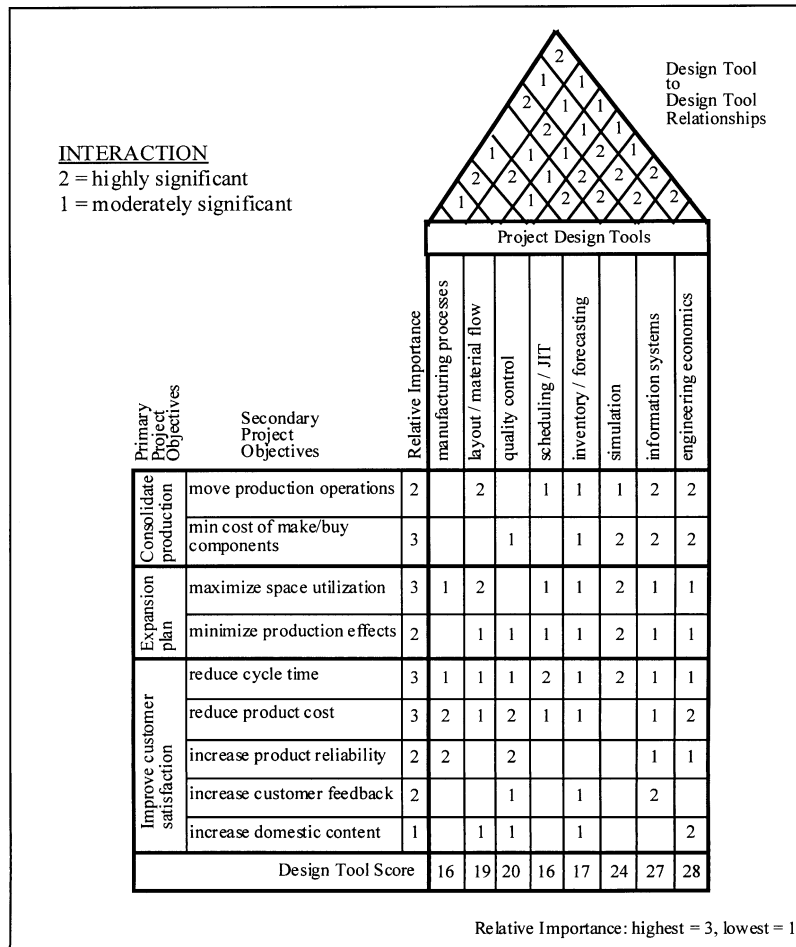


Fig. 5. QFD chart for specific capstone design project #2.

degree and as a result cell design done correctly requires the integration of material that they have learned in other courses. Overall, the use of the QFD diagram helps the team focus their efforts and understand how the topics that they have been taught fit together to solve problems of real significance.

After constructing the QFD diagram the teams seek to obtain guidance for their design projects. In Fig. 4 it becomes apparent that the project is focused on setting up a cell-based manufacturing system. Apart from the obvious need to used group technology techniques, there was a need to utilize existing, as well as create new, information systems to support the analysis. In Fig. 5 the focus of the project was more on the general design tools of simulation, information systems, and engineering economics as the project is focused on a major system change. One theme that tends to consistently surface and surprises the students is the need for a strong information system to provide data for analysis. This is one component of problem solving that they do not experience prior to the actual industrial-based project, since most problems that they have had to solve previously have come from textbooks and have focused on small problems with minimal data

requirements. The QFD diagram helps them to realize the interactions between the various data requirements and how to use data for a variety of different analysis tools.

*Additional techniques for fostering a systems perspective in problem solving*

The QFD framework alone is not sufficient to promote the desired curriculum integration. It is only a tool to analyze the relationships between design tools/course topics and design objectives. There still is a need to utilize this tool to foster a broader systems perspective in design. The following presents two approaches for a systems perspective in engineering design.

The first approach for fostering systems integration is to simply tell students to stop working in panic mode and think about integrating issues related to their design effort. Students need the opportunity to consider new relationships between topics without initial evaluation. Within a QFD problem framework the relationships between design objectives and design tools provide abundant opportunities for students to begin to understand the interrelationship between what they have learned. However, what is typically lacking in engineering education is the opportunity

to utilize the left brain thinking mode in problem solving. Felder [3] gives several suggestions on how to promote creative abilities that would support systems integration and could be used within the QFD framework. These suggestions include open-ended questions, brainstorming, and students making up problems.

A second approach for fostering a systems view is embodied in the principles of 'Breakthrough Thinking' by Nadler and Hibino [9]. Their seven principles for problem solving are:

- uniqueness
- purposes
- solution-after-next
- systems
- limited information collection
- people design
- betterment timeline.

The essence of the principles is that to make breakthroughs one needs to broadly define the problem, consider the long-term ramifications, consider the integrated nature of the problem, and plan for replacement or betterment of the proposed solution. When design constraints are encountered then the constraints should be considered as a positive, not a negative. Constraints require you to go to the next level of a problem in order to resolve the point of contention, implying a need for an integrated system view in order to achieve a solution. Exploring the impact of constraints can many times lead to truly integrated designs.

As an example of 'breakthrough thinking' the UMC-IE Capstone Design class is required to design a new industrial engineering curriculum. The aspects that require an integrated approach are: uniqueness (what about UMC is unique with respect to other IE programs—therefore, how do

we fit into the larger educational system), purposes (what is the objective of an IE program—at what level of the societal/educational system do you take as your objective, i.e. is the objective for student to get a degree so that they can get a job or is the objective to provide an education that will support employer competitiveness), solution-after-next (how is the environment changing in which students will work, i.e. technology, compressed market time), systems (what are the issues that affect and or constrain an IE program, i.e. facilities, accreditation), people design (what are the different stakeholders and their roles, i.e. student, parents, faculty, administrators, industry, government), betterment timeline (adds another dimension to the integrated systems design). The 'breakthrough thinking' approach is just one more technique that can be used to foster a more integrated approach to problem solving.

## SUMMARY

The need for engineers that are creative and can solve real problems has always been apparent. However, the need for engineers that integrate their engineering knowledge, specific design objectives, and decision making in a systems context has recently become a concern. Therefore, the challenge before engineering educators is to provide an educational experience so that integrated design problems can be addressed from a larger systems perspective. It has been the goal of this paper to illustrate one approach for promoting engineering curriculum integration and to encourage others to consider this issue and begin to adopt and/or develop better approaches for teaching integrated engineering design.

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