A Design Attribute Framework for Course Planning and Learning Assessment

Michael J. Safoutin, Cynthia J. Atman, *Member, IEEE*, Robin Adams, Teodora Rutar, John C. Kramlich, and James L. Fridley

***Abstract*—A new method for course planning and learning assessment in engineering design courses is presented. The method is based upon components of design activity that are organized into a design attribute framework. The learning objectives of design courses can be expressed within this framework by selecting from among these components. The framework can also be used to guide the development of survey instruments for use in assessment. These two uses of the design attribute framework are illustrated in the context of a freshman engineering design course.**

***Index Terms*—Assessment, engineering design, surveys.**

I. INTRODUCTION

A RENEWED emphasis on instruction in engineering design [1]–[4] and demands for evidence of the quality of an education [5]–[7] have exposed a crucial need for formal methods for evaluating design courses. A well-grounded assessment plan has three components [8]: a statement of educational goals, a valid set of instruments to measure achievement of these goals, and a plan for utilizing the results from the assessment to inform policies to improve the educational process. This expanded definition of assessment moves beyond assuring minimal competency to making judgments about instruction and curricula with an aim toward improvement [9]. As a result, the teaching and learning process becomes the core of assessment in terms of investigating both the phenomenon and outcomes of students' learning, and the processes and conditions that lead to the kinds of learning one cares about [9].

This vision of assessment is consistent with new requirements in accreditation policies for engineering programs. More specifically, the implementation of the ABET EC-2000 criteria will require engineering programs to identify, assess, and demonstrate evidence of design competency, as well as to provide evidence for how assessment practices inform the continuous improvement of engineering design courses and programs [7]. Without a plan for continuous evaluation, educators lack appropriate and reliable information to modify existing curricula to improve outcomes, improve assessment measures, or change statements of learning objectives [10]. Therefore, a continuous evaluation plan would originate with the articulation of learning objectives and outcomes that reflect appropriate course goals and realistic expectations of students' abilities [11]. From the standpoint of an engineering design experience, these objectives and outcomes would emphasize that design is a cognitive activity that encourages the development of analysis, synthesis, and evaluation skills within the context of engineering practice [12], [13].

This paper presents the *design attribute framework*, a systematic approach for evaluating curriculum and for assessing student learning of design knowledge and skills. The primary feature of our approach is a common framework for articulating individual components of design ability at various categories of understanding. Application of the approach facilitates a collaborative link between researchers in engineering education and engineering faculty and serves to integrate and promote a focus on teaching and learning. Also included in this paper is an illustration of this method as applied to course planning and assessment of student learning for a freshman-level engineering design course.

II. STRATEGIES

A. Attribute Frameworks

The design attribute framework was developed as part of a broader research project that seeks to identify assessment methods that could be used by engineering programs to meet the requirements of the EC-2000 engineering accreditation standards [7]. The project focuses on the 11 learning outcomes of Criterion 3, commonly referred to as "a thru k" [7]. An initial goal of the project is to develop a comprehensive list of attributes that represent student learning of each of the 11 learning outcomes [14].

The driving force behind the larger research project is the observation that ABET's learning outcomes do not detail learning attributes specific to any instructional goal. To apply the 11 outcomes for the purposes of course planning or learning assessment, it is helpful to break down each outcome into finer detail that can be more easily matched to specific course content. One method for providing finer detail is an attribute framework that characterizes two important dimensions of a given learning outcome: individual components of the outcome and nature of student understanding of each component.

Thus, developing an attribute framework for a given outcome presents two challenges. The first challenge is the expression of the outcome in terms of components that are sufficiently complete and detailed for use in broad instructional settings. For example, outcome (c), which concerns the ability to perform engineering design, might be broken into a number of components that represent various categories of design activity, such as problem definition, information gathering, idea generation, and

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Manuscript received August 1, 1999; revised November 29, 1999. This work was supported by the National Science Foundation under Grant NSF-9872498.

The authors are with the College of Engineering, University of Washington, Seattle, WA 98195-2180 USA.

Publisher Item Identifier S 0018-9359(00)04309-0.

TABLE I
Selected Cognitive and Affective Categories of Bloom's Taxonomy

Cognitive Domain	
Category	***Description***
Knowledge	Remembering previously learned information
Comprehension	Grasping the meaning of information
Application	Applying knowledge to actual situations
Analysis	Breaking down objects or ideas into simpler parts and seeing how the parts relate and are organized
Synthesis	Rearranging component ideas into a new whole
Evaluation	Making judgments based on internal evidence or external criteria
Affective Domain	
Category	***Description***
Valuation	That a thing, phenomenon, or behavior has worth

so on. If more detail is desired, each component could be broken down into subcomponents of even finer detail, so that potentially every lecture or instructional activity in a course could be mapped to a specific component or subcomponent of an ABET outcome.

The second challenge is the selection of a means to represent nature of understanding associated with specific components of an outcome. This is necessary because, while the identification of components and subcomponents adds detail, it does not address the type of understanding of each component that a student might be expected to demonstrate. Being able to make this distinction in the context of a given component of the outcome is important because, for example, advanced courses and introductory courses may involve similar components of an outcome but at a different complexity of understanding.

To represent the nature of understanding of each component, the categories of Bloom's taxonomy of educational objectives were adopted [15]. Bloom's taxonomy was originally developed as a means of systematically categorizing educational objectives in a way that facilitates communication among educators [15]. The six major categories of the cognitive domain are shown in Table I. These six categories are said to represent educational behaviors from simple to complex, and are based upon the supposed degree of complexity of the cognitive process involved in their demonstration. To these six cognitive categories a seventh was added—the valuation category of the affective domain. This was done to broaden the ability to represent affective goals that may be important, or even central, in some subject areas.

It is important to note that during the years that Bloom's taxonomy has been in use, issues have been raised concerning the validity of the taxonomic model and the implications of its use in education. For example, while Bloom acknowledged the possibility of variation in the sequencing of the categories [15], the taxonomy is generally taken to be both hierarchical (each level describes a behavior of increasing complexity) and cumulative (each successive level includes the behaviors of the previous levels) [16]. This assumption has been examined with mixed results. Although methodological difficulties make it difficult to conclusively validate its structure [17], evidence tends to support the cumulative and hierarchical properties of the first four levels [18], [19], with the placement of the synthesis and evaluation levels being less clear [20]. In addition, the taxonomy has been questioned because of the effect that it could have on instruction sequencing if employed prescriptively. Such debate suggests that Bloom's taxonomy be used with caution. As previous education practitioners have discovered, this taxonomy had proven to be a powerful tool to organize information about educational objectives and to communicate this information to others.

B. Design Attribute Framework

The work is focused on the development of an attribute framework for outcome (c) of a–k, which ABET describes as "an ability to design a system, component, or process to meet desired needs" [7]. Although there are other outcomes that include skills related to engineering design, outcome (c) addresses engineering design more specifically than any other, so this framework is referred to as the design attribute framework.

To express the components of this outcome, a two-tiered approach was adopted in order to achieve two degrees of detail. At the most general level, engineering design was broken down into *components*, or categories of activity that resemble the steps or phases of many traditional design process models. These categories were initially based on a set of "design steps" previously developed for use in verbal protocol coding [21]. To be certain that the list of components was as complete as possible, a large number of published models of engineering design and the design process were gathered and reviewed [22]. The design activities mentioned in each model (for example, "identify basic needs," "establish design objectives," "ideate and create") were abstracted and grouped into the components that they best matched (for example, "need recognition," "problem definition," "idea generation"). In some cases, a design activity described in a design model did not fit well into any of the existing components, and a new component was initiated. For example, the Planning category was added to represent the initial planning of the design process, which was not clearly represented in the initial component set. At the more detailed level, each component was then broken down into individual *subcomponents* representing more specific elements of the component, again by examining the elements of each design model that was reviewed. The two-tiered approach led to two lists of outcome components at two levels of detail, referred to as the *component level* and the *subcomponent level*. The resulting list of components and subcomponents for outcome (c) is provided in the Appendix.

The design attribute framework emerges when the components and/or subcomponents of outcome (c) are placed along the vertical edge of a grid, and the cognitive categories of Bloom's taxonomy are listed across the top. This creates a table of cells, each corresponding to a single component/cognitive-category pair. Each cell thus represents a specific *attribute,* of outcome (c) in terms of one aspect of design within one cognitive category. Finally, at least one attribute or specific learning objective was identified and associated with each pair. The set of attributes thus defined is comprehensive and suggestive, but not exhaustive.

In its simplest form, the design components alone are expressed, to create what is called the component-level design attribute framework [22], a portion of which is shown in Table II. Each row within this framework describes one component of

TABLE II
PORTION OF THE COMPONENT-LEVEL DESIGN ATTRIBUTE FRAMEWORK

Outcome (c):
The ability to design a system, component, or process to meet desired needs.

	Cognitive Categories			
Components of Outcome (c)	*Knowledge*	*Comprehension*	*Application*	*Analysis*
Need Recognition	Recite definitions; name established methods and list their steps	Describe differences between different methods; carry out steps in a hypothetical design situation when asked	Select and perform appropriate method at a proper stage of a design project	Analyze perceived wants and needs to isolate the most relevant needs
Problem Definition	Recite definitions; name established methods and list their steps	Describe differences between different methods; carry out steps when asked	Select and utilize appropriate method for problem definition; successfully produce problem definition at an appropriate stage of a design project	Analyze a needs statement to isolate information pertaining to problem definition
Planning	Recite definitions; name and list steps in design process; list established management strategies and their elements	Describe differences between different design steps; carry out steps when asked	Select and perform appropriate design stage at an appropriate point in a design project	Analyze progress of design in order to revise plan as needed
Management	Name project monitoring techniques; list their elements and applications; list methods to modify design plans	Describe differences between different techniques; modify a given design plan given a situation	Select and perform appropriate monitoring, modification method during a design project	Analyze progress of design in order to revise plan as needed; analyze errors to determine proper reaction

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outcome (c) in terms of behaviors that indicate performance of the component at various degrees of cognitive complexity. For example, a student is demonstrating Comprehension of the Problem Definition component if he or she can "describe the differences between methods of problem definition" and "carry out the steps (in each method) when asked."

Since each component has subcomponents, greater detail can be achieved by including the subcomponents in the framework. The result is the subcomponent-level design attribute framework [22]. A portion of this framework, showing some subcomponents of the Planning step, is depicted in Table III.

C. Using the Design Attribute Framework

The development of attribute frameworks, in general, is intended to transform the relatively imprecise ABET learning outcomes into information that can be used in the characterization of courses and the development of assessment instruments. The component-level design attribute framework has a coarse level of detail that resembles traditional process models of design, making it accessible and straightforward to apply to the general characterization of instructional material. The added detail of the subcomponent-level design attribute framework provides a richer source of more precise outcomes that an educator may use to develop highly targeted assessment instruments.

The design attribute framework has been used in connection with a freshman engineering design course at the University of Washington. This experience investigated two key activities that are facilitated by the framework: the opportunity to systematically represent and compare the learning objectives of course material, and the opportunity to isolate highly specific learning outcomes. The first example shows how the component-level design attribute framework was used to evaluate the learning objectives of an introductory design course, by providing a systematic method of representation and comparison of the learning objectives of each design project module in the course. The second example illustrates the use of the subcomponent-level framework in developing a survey instrument to assess student learning in this course.

III. COURSE PLANNING

One challenge in describing a course is to be able to concisely describe the learning objectives associated with specific activities within the course. Such descriptions make it possible to verify that the course activities lead to the desired learning

TABLE III
PORTION OF THE SUBCOMPONENT-LEVEL DESIGN ATTRIBUTE FRAMEWORK SHOWING ATTRIBUTES FOR SELECTED SUBCOMPONENTS OF PLANNING

	Cognitive Categories		
Subcomponents of Planning	*Knowledge*	*Comprehension*	*Application*
Develop a design strategy (a process for identifying and performing tasks):	List elements of design process models	Develop a strategy based on a given model of the design process	Develop a strategy based upon the most appropriate model of the design process
Decompose problem into subtasks	List attributes of a good decomposition	Distinguish between good and poor decompositions	Develop a good task decomposition when planning a design strategy
Prioritize tasks appropriately	List attributes of good prioritization	Distinguish between good/poor suggested prioritizations	Select an appropriate technique for prioritizing subtasks in a design setting
Create realizeable timetables and milestones	List techniques to establish timetables, milestones	Carry out a specified technique to create timetable, set milestones	Select and carry out an appropriate technique in a design setting

opportunities, both individually and collectively. In addition, such descriptions allow the comparison of different activities, leading to a better understanding of their individual contributions to the overall learning experience. This section describes how the component-level design attribute framework was used to create high-level profiles of some instructional activities in a freshman design course and subsequently to better understand the individual and collective nature of these activities.

A. Freshman Design Course: Engineering 100

Traditional engineering curricula emphasize engineering science fundamentals in the first two years, with design courses being introduced only in the junior and senior years. ENGR 100 is a freshman-level design course offered as an elective by the College of Engineering at the University of Washington. The course has two very broad objectives. One of these objectives is to impart specific skills associated with design and teamwork at an early point in the curriculum. The second is to provide an opportunity for the students to envision their place in the profession at the start of their college studies [23].

With regard to specific skills, the goal is for students to experience open-ended problem solving in teams at an early enough point that the skills developed can be used throughout their academic careers. The specific areas emphasized in ENGR 100 include experiencing the steps of the design/problem solving process, appreciating the role that math and science play in design, describing the role of engineering analysis in design, working effectively in teams, and selecting and using effective methods of written and oral technical communication.

With regard to the profession of engineering, the objective in ENGR 100 is to provide a snapshot of what an engineer does. This allows the students to see the appropriate role for their fundamentals and analysis classes, provides motivation for the study of these fundamentals, emphasizes the importance of teamwork and communication skills, and builds enthusiasm. Another goal is to increase retention by ensuring that students do not leave engineering for the wrong reasons.

Instructional activities are focused around two to three extensive design modules and several shorter design exercises. Each module is structured to provide a realistic exposure to team problem solving and to illustrate the importance of communication skills in reporting outcomes. Also, each module contains some implementation of math and science fundamentals and engineering analysis. ENGR 100 is designed to maximize interaction between students and instructors by having a high instructor-to-student ratio and by constant contact between them during class.

The first two weeks are devoted to introducing students to the significance of design in engineering practice, processes for solving design problems, and effective group and communication skills. A simple ice-breaker exercise, the Spaghetti Cantilever Design Exercise [24], is performed on the first day of class. Students form teams to build a simple cantilever device from pieces of dry spaghetti and tape. The instructor compares the results of each team and asks the students to describe some of the steps they found themselves performing. These are then related to the steps of the engineering design process. Over the next two weeks, two additional exercises call for their first conscious implementation of design steps and continue to reinforce the importance of written communication in documenting designs.

In the third week, students begin one of the three large design modules. The requirement is to build a model truss bridge using wooden tongue depressors and other assigned materials, in a competition to achieve the highest score based on performance and cost. Before beginning the design of the bridge, students perform experiments to learn what governs the strength of

Learning Objectives for ENGR 100 Bridge Project
• Work in teams
• Define functional requirements and constraints imposed on the design
• Perform design component testing and analyze the results
• Use these results during brainstorming
• Identify at least three possible bridge designs during brainstorming
• Choose one of the designs by using arguments based on knowledge gained during component testing, by general knowledge of physics, and by general observations of existing bridges
• Build and test the prototype
• Redesign
• Build and test the final design
• Present the design to other teams
• Write a report describing the design

Fig. 1. Project learning objectives provided by course instructor.

each of the components and the various ways these components fail. They also perform a static analysis of a simple triangular truss to predict how it will fail under an imposed external load, and then verify their prediction via experiment. Using this insight, students design an initial prototype and test it to failure. They then analyze the failure mode and create a modified final design and again test it to failure in a competition. The student teams are required to document the entire design process in two memoranda, a final report, and a team presentation.

A product dissection exercise is introduced midterm. The students disassemble a lawnmower engine [24], document the procedure in sufficient detail to reassemble it, reassemble it to working order, and write a detailed report. The report includes a detailed operational description of each engine part, which students learn during dissection by observation and by discussion with instructors. It also includes engineering estimates of performance made by applying basic scientific principles.

The final project is a tug-of-war competition in which the students design a device that competes against other student devices. Student teams are left to design their devices relatively independently, managing their time and effort as they see fit given a severe time constraint and using only a supplied set of erector-type components. When the designs are completed, they perform simple power and energy tests to predict performance and optimize their design before the competition. After the competition, students submit an extensive final report in which they are asked to explain the relation between the performance of their device in the simple tests and in the final competition, and to recommend improvements to the design.

B. The Learning Objectives Profile

Courses within a design curriculum can often be distinguished by differences in the specific design skills they emphasize and the complexity of understanding that students are expected to demonstrate. These differences may often be detected in the stated learning objectives of the course. To plan and improve course content, it is important to be able to evaluate a course to confirm that its learning objectives are in fact supported by the course instruction. The design attribute framework leads to a systematic method for representing and comparing learning objectives of course material. By mapping a list of learning objectives to the two-dimensional design attribute framework, one can represent learning objectives visually. The visual representation improves comparison and understanding by making explicit the areas of emphasis and the complexity of understanding that are actually addressed by the material being profiled.

Four projects from the freshman design course were profiled. First, the instructor was asked to list the learning objectives of each project. The question was posed as, "What skills do you hope to develop by having the students do this project?" Objectives were stated in generic terms relating to engineering design skill categories rather than content specific terms. For example, if a project includes simple truss analysis, the objective would be stated as "use engineering analysis in a design problem" rather than "perform simple truss analysis." Each learning objective was then categorized by the component that it best represented. For example, the learning objectives provided by the instructor for the Bridge project are shown in Fig. 1. Next, it was necessary to establish the cognitive capability that the students were expected to develop with regard to this component. This is like asking the question, "Is the learning of this *component* of design at this *cognitive category* one of the purposes of this project?"

The learning objectives were then mapped to the design attribute framework. This was done by placing the represented components on a worksheet resembling a blank version of the component-level design attribute framework and drawing horizontal bars at each component to represent the most complex cognitive category expected of the students. The collection of bars thus creates a visual profile of the project in terms of design components and cognitive categories. The resulting profile for the bridge project is shown in Fig. 2. It can be seen that its learning objectives are fairly well distributed among the design components, with each component typically represented at the Comprehension or Application cognitive category. This is consistent with the typical goals of an introductory design course. Note that the components Planning, Management, and Modeling are not represented in this project.

As expected, the three other projects in the course (projects 1, 3, and 4) were found to emphasize different sets of components at different cognitive categories (Fig. 3).

Project 1 is the Spaghetti Cantilever exercise described earlier. Idea generation and communication are profiled as

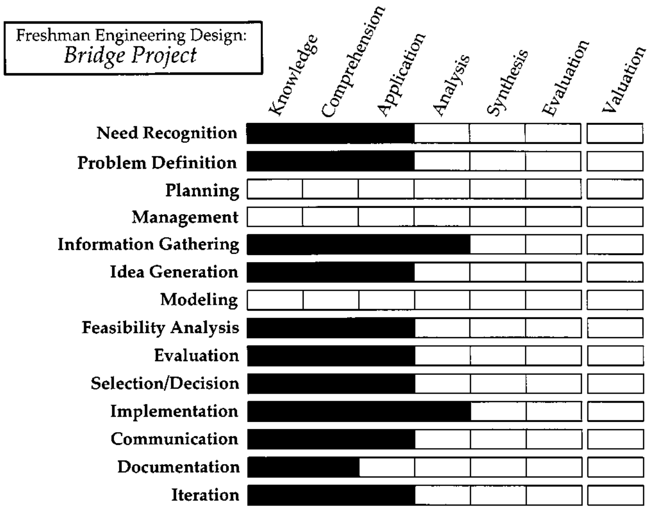


Fig. 2. learning objective profile for Bridge design project.

dominant aspects, along with some representation of need recognition, problem definition, planning, feasibility, evaluation, selection, and implementation. Since the project context is tightly defined by the instructor and the project terminates with the building of a single design concept, it is consistent that the other design steps are not represented.

The profile of project 3, the engine dissection exercise, provided new insight. Few of its learning objectives could be readily categorized under the design attribute framework. It became clear that this project is not a design project in the same sense as the other projects, and so would not be fully characterized by the design attribute framework. On reflection, the instructors indicated that the project was designed primarily as a context-setting exercise that empowers the students by helping them understand the engine as an engineering product, by removing the mysteries of its operation, and by making the students more confident in working with physical parts and complex mechanisms. The engineering analysis questions were included in order to further relate the dissection experience with engineering practice. Thus the focus of this project is to teach a lesson about the design profession, but not necessarily through a design project. The profiling of this exercise highlighted the difference in learning objectives between dissection activities and design projects, and made this distinction more explicit in the minds of the instructors, not all of whom had employed this distinction in introducing the module to the students.

The tug-of-war project (project 4) is the final project of the term. As one would expect of a final project, its profile shows that it calls for performance of a broad spectrum of the design components in a relatively complex cognitive category (Application) and emphasizes Documentation and Communication more than the other projects.

C. Insights of the Learning Objective Profile

The profiles of the freshman design projects presented in the previous section are a high-level description of the learning objectives for student performance for which each project was designed. The profiling exercise confirmed some expectations and provided new insights. As expected, the differences in the objectives of each project were clearly expressed in the profiles, and few of the objectives for this introductory course ventured beyond the Application category.

Instructors gained insight. Although they had expected that the projects as a group touched upon every important aspect of engineering design, the profiles showed that none of the projects covered the Management component. The Information Gathering and Modeling components also were unexpectedly weak. The instructors speculated that these shortcomings were partly due to tightly controlled project definitions and short time frames allotted to each project (as little as one week).

The profile of the product dissection exercise reminded the instructors that this exercise had additional goals beyond the teaching of the design process, although they had routinely referred to it as one of the "design" projects, to each other and to the students. This realization has provided an opportunity to improve the students' perspective of engineering by pointing out its distinction from the other design projects and the reasons for including it in the course.

As a high-level description, the profiles are powerful. At the same time, they can mask several complexities. First, one should recognize that these profiles represent only one feature of the instructional context—the performance expected of students in completing the project. If the focus were instead on the content actually presented in lecture material or project descriptions, the bars might not be cumulative but rather might need to be completed on a cell by cell basis. For example, since the emphasis of the instruction in ENGR 100 is not on teaching "facts" about design, then if the projects were profiled on the basis of what is presented instead of the performance expected, the profiles might leave many of the Knowledge cells unshaded. Second, the undifferentiated shading of the cells masks possible differences in the specific subcomponent-level focus within a given component. For example, a project that requires the drafting of a memorandum might cover the Communication component at the Application level, yet its profile would be indistinguishable from that of another project that requires a full report. Extending the profile to include the subcomponents of each component might alleviate this shortcoming. Finally, the current profiling technique, because it was focused on design components exclusively, does not represent more diverse aspects such as ethical and professional responsibility or lifelong learning, which may be important aspects of some projects. While each of these complexities can be addressed, it is important to recognize that the goal was to create a high-level description that can serve as a basis for comparison, verification, and communication of objectives, specifically with respect to outcome (c). A more complete evaluation and assessment toolbox might include additional frameworks developed from each of the ten other ABET outcomes.

IV. LEARNING ASSESSMENT

In the previous section, the design attribute framework was used to profile and evaluate learning objectives for ENGR 100 design modules. This section will employ the framework to develop an instrument to assess student learning.

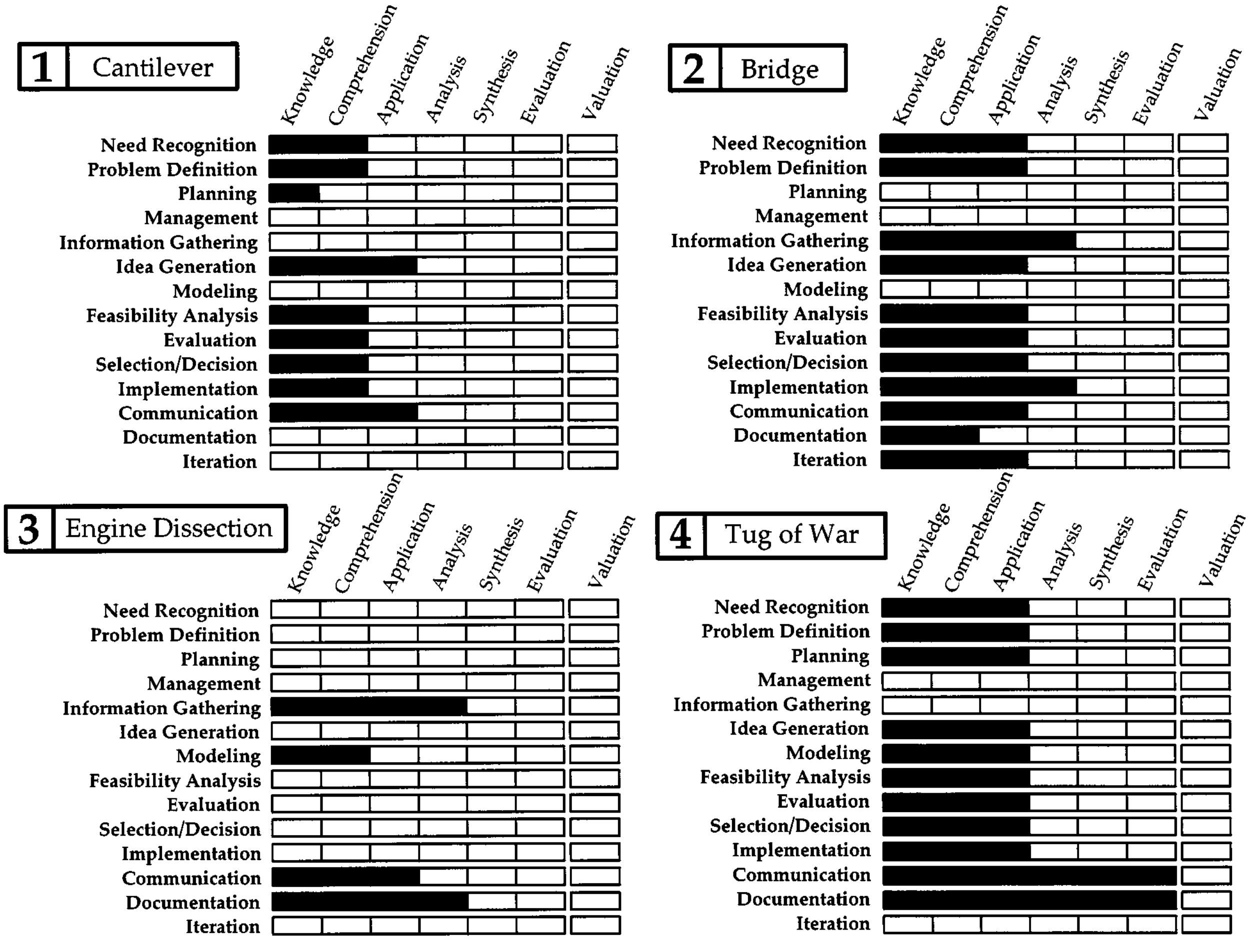
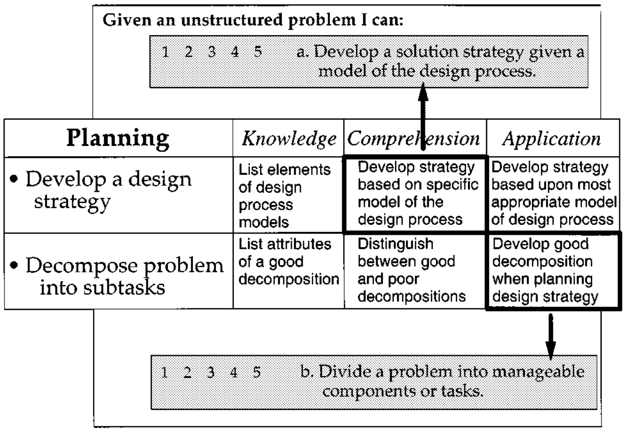


Fig. 3. Learning objective profiles across four freshman design projects.

A. Assessing Student Learning

The learning that results from authentic tasks in an open-ended environment is not easy to assess with traditional tests or existing instruments. Surveys are a measurement tool that can provide a means for measuring an ability to undertake complex activities that require selecting relevant knowledge and skills and applying these to the solution of a problem. Surveys can be relatively simple to administer, are easily replicated for large numbers of subjects, and provide quantitative feedback for statistical analyses [25], [26]. Unfortunately, good surveys are difficult to design. They are especially difficult when learning objectives are ill-defined or ambiguous.

Using the design attribute framework to develop the survey helped overcome this difficulty by providing explicit and cognitively based definitions of design ability in measurable terms. This framework articulates learning outcomes at various levels of detail and pinpoints the desired areas of student learning to be assessed. As a result, survey questions were developed that focused on performance and how students approach design problem solving, rather than on recall of information. Also, use of a common framework to assess learning and to profile instructional activities maximizes the utility of the survey instrument by providing assessment results with clear implications for evaluation and improvement.



Given an unstructured problem I can:

1 2 3 4 5 a. Develop a solution strategy given a model of the design process.

Planning	Knowledge	Comprehension	Application
• Develop a design strategy	List elements of design process models	Develop strategy based on specific model of the design process	Develop strategy based upon most appropriate model of design process
• Decompose problem into subtasks	List attributes of a good decomposition	Distinguish between good and poor decompositions	Develop good decomposition when planning design strategy

1 2 3 4 5 b. Divide a problem into manageable components or tasks.

Fig. 4. Development of survey questions from the subcomponent-level design attribute framework.

B. Assessment Instrument

Survey questions were developed by locating specific cells on the subcomponent-level design attribute framework that best represented specific design subcomponents at cognitive categories appropriate to the learning objectives of ENGR 100. Because this course was intended to be a student's first introduction

VI. For the following statements about solving unstructured problems (e.g., problems that have no single "right" answer), indicate your <u>level of confidence</u>. For example, if you have little or no confidence in your ability to recognize the needs to be addressed by the problem, then mark poor. If you are extremely confident of your ability, mark <u>excellent</u>.

Given an unstructured problem (I can):

Design Component		Poor	Fair	Good	Very Good	Excellent
Need Recognition	Recognize the needs to be addressed by the problem.	1	2	3	4	5
Need Recognition	State the needs of the problem in clear and explicit terms.	1	2	3	4	5
Problem Definition	List the performance requirements that a solution must satisfy.	1	2	3	4	5
Problem Definition	Establish criteria for evaluating the quality of a solution.	1	2	3	4	5
Planning	Develop a solution strategy given a model of the design process.	1	2	3	4	5
Planning	Divide a problem into manageable components or tasks.	1	2	3	4	5
Information Gathering	Identify the knowledge and resources needed to develop a solution.	1	2	3	4	5
Information Gathering	Ask probing questions to clarify facts, concepts or relationships.	1	2	3	4	5
Idea Generation	Describe procedures or techniques to search for and generate solutions.	1	2	3	4	5
Idea Generation	Generate possible alternative solutions.	1	2	3	4	5
Modeling	Select a mathematical model that can be used to characterize a solution.	1	2	3	4	5
Evaluation	Identify the pros and cons of possible solutions.	1	2	3	4	5
Evaluation	Compare a set of solution alternatives using a specified set of criteria.	1	2	3	4	5
Feasibility Analysis	Analyze the feasibility of a solution.	1	2	3	4	5
Feasibility Analysis	Identify feasible solutions.	1	2	3	4	5
Selection	Select a solution that best satisfies the problem objectives.	1	2	3	4	5
Implementation	Build a prototype or final solution.	1	2	3	4	5
Documentation	Document your solution process.	1	2	3	4	5
Communication	Understand the different roles and responsibilities of being an effective member in a team.	1	2	3	4	5
Communication	Resolve conflict and reach agreement in a group.	1	2	3	4	5
Communication	Identify the characteristics of effective communication.	1	2	3	4	5
Iteration	Recognize when changes to the original understanding of the problem may be necessary.	1	2	3	4	5
Iteration	Suggest modifications or improvements to a final solution.	1	2	3	4	5
Iteration	Develop strategies for monitoring and evaluating progress.	1	2	3	4	5

Fig. 5. Survey instrument based on selected design components.

to the design process, the focus was on those cells of the framework that mapped to lesser complex categories of Bloom's taxonomy (e.g., Comprehension and Application). Some cells were selected at the Evaluation level to reflect the range of skills and knowledge necessary to perform some of the more advanced design components.

For the purposes of illustration, an example of this process for a survey question generated for the Planning component is provided. Fig. 4 shows a portion of the subcomponent-level framework focusing on the subcomponents of Planning. The fine detail provided at the subcomponent level provides an opportunity to frame very specific questions. For example, if a survey designer wishes to assess achievement at the Comprehension cognitive category for the subcomponent *developing a design strategy*, the contents of the corresponding cell may be transformed directly into a survey question as shown in Fig. 4.

Fig. 5 shows a list of questions generated for use in ENGR 100. For each design component, students are asked to rate their confidence in their ability. The design component that each question addresses is indicated in the left-hand column but is not included in the actual survey.

To minimize some of the disadvantages of using surveys as a measurement method, the following guidelines were adopted: open-ended questions were included to cross-validate survey items, biased phrasing and negative questions were avoided to limit misinterpretations, and multiple statements were included to control response errors [25], [26]. Also, the instrument was pilot tested to address content clarity and usability of data by

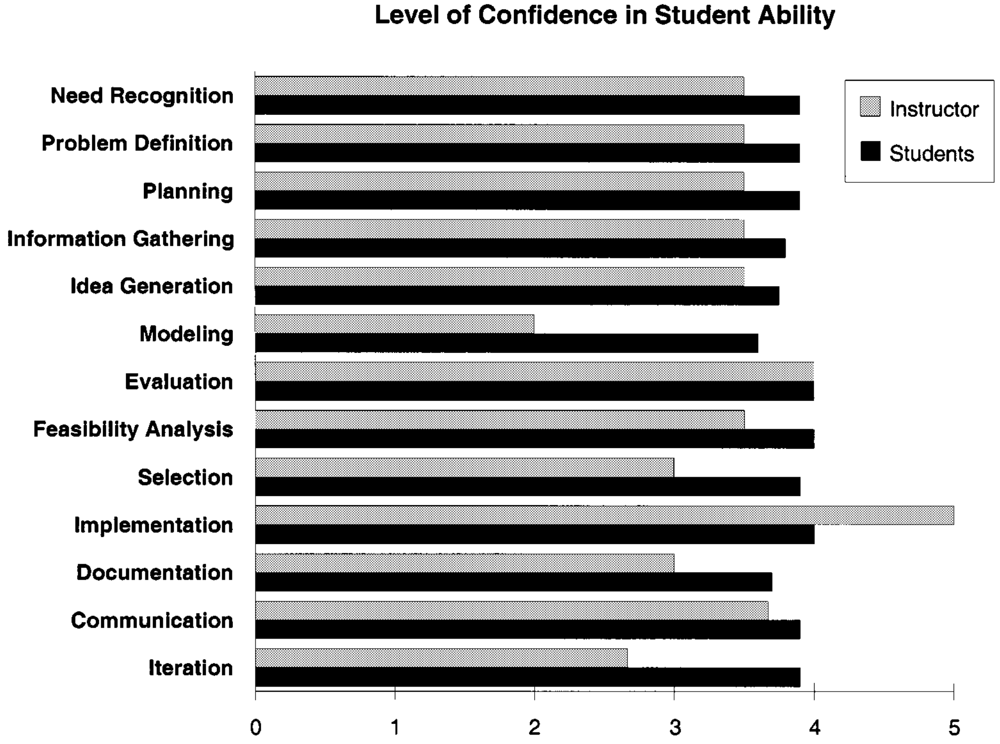


Fig. 6. Differences between instructor confidence in students and student confidence in self, pilot study.

administering it to one section of ENGR 100 as a postsurvey at the end of Spring quarter 1999.

Analysis of the pilot survey data has allowed exploration of ways in which the survey can be used. First, the students' level of confidence within each design component was considered. Second, instructors were asked to rate their perception of their students' abilities as a class, to allow comparison of the students' perceptions to that of the instructor. Fig. 6 summarizes the responses gathered from one instructor's class in the pilot survey. In a sample size of 25, the mean student response for each question was relatively flat and did not reveal significant trends. The difference between instructor confidence and student confidence was more suggestive. The general trend suggests that the instructor had higher confidence in the students' abilities in the more basic stages of the design process and a lower confidence at more complex or advanced stages. This trend would be consistent with an introductory course. For this instructor, the difference in confidence was most significant in the areas of Modeling and Iteration (the instructor's opinion being lower than that of the students).

To cross validate items and verify reliability of this instrument, a multiple methods assessment plan was implemented for the full Fall 1999 ENGR 100 cohort. It included pre- and postsurveys to track changes over the course of the quarter. Data from both surveys are currently being analyzed.

Several changes to the format and content of ENGR 100 have been initiated or reinforced by the results of the Spring 1999 pilot study. The project profiles suggested that Management, Planning, Modeling, and Iteration were not as well represented by the existing projects as the instructors had wished. In the case of Modeling and Iteration, the instructors' responses to the survey reinforced these findings. Three major refinements to the course have been initiated and now address these shortcomings. First, the Bridge design project has been revised to include the use of structural modeling software in testing preliminary bridge designs. This supplies more experience with modeling and allows the students to iterate more because the modeling software allows the rapid testing and revision of many more alternatives than before. Second, a cross-cultural section of ENGR 100 was developed during the Fall quarter, in which students work on a greater diversity of projects than in the traditional sections, and collaborate in teams with students enrolled in a sister course at Tohoku University in Japan. This is expected to create a greater awareness of management, communication, and teamwork issues than in the traditional sections. Finally, one project in this section involves the design of a windmill, with extensive use of rapid prototyping in generating and testing alternative blade designs. This project is being considered for inclusion in the standard sections to additionally reinforce the presence of iteration and modeling.

V. CONCLUSIONS

As shown by the example, the design attribute framework provides a common language for profiling learning objectives and creating survey instruments. Sharing a common language for describing instructional activities, comparing learning objectives to instructional activities, and assessing students' perceptions of their design knowledge and skills promotes continuous feedback. Feedback from assessing student learning can be used to refine faculty expectations of the level and quality of student performance, help identify areas of improvement in instructional practices, and make descriptions of performance in grading practices more meaningful. Also, feedback from monitoring instructional goals and activities encourages faculty awareness of pedagogical issues, refinement of course learning objectives, and institutionalization of classroom assessment practices.

This approach was based on a collaborative effort between engineering education researchers and instructors. Taking a collaborative approach to continuous evaluation connects teaching to learning [27] and continual improvement guided by assessment of student learning [11]. The approach weds internally driven assessment (e.g., curricular reform and pedagogical improvement) with externally driven assessment (e.g., accountability and accreditation) and acts as a stimulus to reflective practice [9].

APPENDIX
COMPONENTS AND SUBCOMPONENTS OF OUTCOME (c)

Need Recognition: Identify needs that are to be served by the design, starting with customer's perceived wants and societal need, and clarifying and formalizing them to form a needs statement.

- Identifying needs to be served by the design.
- Seek understanding of perceived needs as described by customer.
- Evaluate societal need and cost associated with product.
- Express an unambiguous needs statement.
- Identify target customers and target market.

Problem Definition: Determining design objectives and functional requirements based on needs statement, identifying constraints on the design problem, and establishing criteria for acceptability and desirability of solutions.

- Transform statement of need to statement of design objectives (functional requirements).
- Establish criteria by which to judge acceptability and desirability of potential solutions.
- Identify constraints on the design problem.

Planning: Development of an initial design strategy, including an overall plan of attack, decomposition of design problem into subtasks, prioritization of subtasks, establishment of timetables and milestones by which progress may be evaluated.

- Develop a design strategy.
- Decompose problem into subtasks where appropriate.
- Prioritize tasks appropriately.
- Create realizeable timetables and milestones.

Management: Guidance of course of action during design and in response to changing conditions.

- Make changes to the initial plan as necessary.
- Revise subtask breakdown as needed.
- Manage time and resources to meet timetable and milestones.
- Keep focused on design goal as design proceeds.

Information Gathering: Gathering information about the design problem, including the need for a solution, user needs and expectations, relevant engineering fundamentals and technology, and feedback from users.

- Gather data to verify the existence of a problem including data on customer perceptions and desires.
- Gather relevant engineering fundamentals and technological state-of-the-art.
- Elicit and incorporate feedback from users.

Idea Generation: Transforming functional requirements/objectives into multiple alternative solutions.

- Transform functional requirements into physical possibilities.
- Employ techniques for generating alternatives systematically.

Modeling: Employment of models/representations/simulations of the physical world to provide information for design decision.

- Recognize appropriate models for representing the physical world in a given situation.
- Employ models to inform design decisions.
- Develop models properly.

Feasibility Analysis: Evaluating feasibility of alternatives or proposed solutions by considering stated constraints as well as implied constraints such as manufacturability, compatibility, cost, and other criteria.

- Evaluate feasibility of multiple alternatives in terms of constraints.
- Check component interfaces for compatibility and design feasibility.
- Recognize unstated constraints such as manufacturability or assemblability in evaluating designs.

Evaluation: Objectively determining suitability of alternatives or proposed solutions by comparing expected or actual performance to evaluation criteria.

- Use evaluation criteria to objectively judge acceptability, desirability of alternatives.

Selection/Decision: Selection of the most feasible and suitable concept among design alternatives.

- Discern feasible solutions.
- Use evaluation to select feasible alternative that best satisfies objectives.

Implementation: Creating an instance of a physical product/process (prototype or final product) for purpose of testing or production.

- Build prototypes or mockups of components or the whole product to test the emerging design.
- Select components from manufacturer catalogs.

Communication: Exchange of information with others, utilizing appropriate formats.

- Initiate and maintain communication with the client about goals and progress.
- Exchange design information with team members using appropriate channels, such as interpersonal communication, design data base.
- Initiate and maintain communication with third parties such as vendors and contractors.

- Present the product or process and documentation to the client.
- Collect feedback from customer.

Documentation: Production of usable documents of record regarding the design process and design state, including decision history and criteria, project plan and progress, intermediate design states, finished product, and use of product.

- Document decisions and decision criteria.
- Keep a journal or other record of design development.
- Create and maintain planning documents and status assessment reports.
- Document the finished product or process as appropriate for the discipline according to standard practice.
- Maintain a design data base that can be used by others charged with constructing or continuing a design.
- Use industry/professional documentation standards.

Iteration: Utilize strategies to inform design decisions that may contribute to a change in a design state (e.g., the problem definition, problem solutions, or design process plan).

- Utilize strategies or procedures for diagnosing and monitoring progress, and incorporating feedback.
- Utilize strategies or procedures for accessing, clarifying and examining information about the problem or a problem solution.
- Incorporate and integrate new knowledge into design decisions (e.g., decisions to modify, improve or elaborate a design state).
- Appraise strategies, procedures and tools in terms of their ability to efficiently generate accurate, useful and meaningful information.

ACKNOWLEDGMENT

The authors would like to thank J. Turns for her valuable input and also the students who participated in the pilot study. The authors would also like to acknowledge the ECSEL Coalition, an NSF-sponsored Engineering Society Coalition, for developing and Institutionalizing ENGR 100 and in the early 1990's.

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Michael J. Safoutin received the M.S. degree in general engineering from the University of Illinois at Urbana-Champaign in 1990. He is currently pursuing the Ph.D. degree in the Mechanical Engineering Department, University of Washington, Seattle.

He was with the Director's Office of the EPA National Vehicle and Fuel Emissions Laboratory and became involved with modeling and policy issues related to the Partnership for a New Generation of Vehicles. At the University of Washington, he coordinated the design and operation of the Integrated Learning Factory design education facility, taught courses in engineering design, and most recently joined the Center for Engineering Learning and Teaching. His research interests include design theory and methodology, theory of design management, artificial intelligence in design, and engineering education.

Cynthia J. Atman (M'97) received the B.S. degree in industrial engineering from West Virginia University, Morgantown, the M.S. degree in industrial and systems engineering from The Ohio State University, Columbus, and the Ph.D. degree in engineering and public policy from Carnegie Mellon University, Pittsburgh, PA.

She is Director of the Center for Engineering Learning and Teaching in the College of Engineering, University of Washington, Seattle, where she also is an Associate Professor of Industrial Engineering. Previously, she was an Associate Professor at the University of Pittsburgh, where she cochaired the 1997 Frontiers in Education conference with L. Shuman. Her research interests include modeling cognitive understanding of technical information and the design process; developing effective communication methods for technical information; and science and engineering education. She teaches courses in human factors engineering and engineering education.

Robin Adams received the M.S. degree in materials science and engineering in 1994 from the University of Washington, Seattle. She is currently pursuing the Ph.D. degree in the Education, Leadership and Policy Studies Program at the University of Washington.

She is the Local Evaluator at the University of Washington for the Engineering Coalitions of Schools for Excellence in Education and Leadership, which is funded under the Engineering Education Coalitions Program of the National Science Foundation. She is also an Affiliate with the Center for Engineering Learning and Teaching.

Teodora Rutar received the B.S. degree from the University of Belgrade, Belgrade, Yugoslavia, and the M.S. degree from the University of Washington, Seattle, both in mechanical engineering. She recently received the Ph.D. degree in mechanical engineering from the University of Washington.

Her current work involves research in combustion. Her area of expertise is analysis of the formation of nitrogen oxides in lean-premixed gas turbine combustors. During her studies, she has been actively involved in teaching and service. She has accepted a position as an Assistant Professor of mechanical and manufacturing engineering at Seattle University.

Dr. Rutar received the Dean's Outstanding Teaching Award for a Teaching Assistant in the College of Engineering, University of Washington.

John C. Kramlich received the B.S. degree in chemical engineering, the M.S. degree in environmental engineering, and the Ph.D. degree in mechanical engineering from Washington State University, Pullman, in 1973, 1975, and 1980, respectively.

He is a Professor of mechanical engineering at the University of Washington, Seattle, and co-coordinator of ENGR 100, Introduction to Engineering Design. He spent 12 years with Energy and Environmental Research Corp., Irvine, CA, rising to Vice President for Process Research. He moved to his present position at the end of 1991. His research focuses on solving the environmental problems associated with energy conversion. His principal contributions lie in the development of the mechanism of nitrous oxide formation in fossil fuel systems, in the discovery and development of the advanced reburning process for NO control in industrial furnaces, and in the development of the mechanism of mercury oxidation by chlorine in coal-fired systems.

James L. Fridley received the B.S. degree in engineering from the University of California, Davis, the M.S. degree in agricultural engineering from Michigan State University, East Lansing, and the Ph.D. degree in mechanical engineering from the University of Washington, Seattle.

He is a Professor of forest engineering at the University of Washington and Cocoordinator of ENGR 100, Introduction to Engineering Design. His research areas include engineering design, computer graphics and graphical simulation, forest engineering, and mechanical engineering.