A Design Methodology for Hands-on Classroom Experiences

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Abstract

The advantages of using hands-on activities to improve design classes are well known. However, a structured design methodology for development of these activities is not available in the literature. This paper presents such a design methodology, borrowing heavily from a product design approach. Innovative features of this methodology include the use of educational objectives as design "functions" and the use of pedagogical theories and learning style information as part of the "analysis" step in the design process. Details of each step in the process are presented. The methodology is used to compare the use of original and redesign projects. This comparison highlights some distinct advantages of redesign oriented hands-on projects.

1. Introduction

There is considerable literature that addresses the advantages of using hands-on experiences in engineering curriculum [1-14]. Although assessment indicates that the incorporation of hands-on experiences almost always improves a given course, there appears to be a dearth of information regarding the effective *design* of hands-on content. This paper presents a structured design methodology, using standard design tools like customer needs analysis, Quality Function Deployment and quantitative decision making [13,15], for designing improved hands-on experiences. One notable innovation in this design methodology is the use of pedagogical theories and learning style information in what would normally be the "analysis" phase of the design process. In particular, this "analysis" phase of design incorporates the learning style information as identified through the use of students' Myers Briggs Type Indicator [16-19] and integrates pedagogical theories such as the Kolb cycle [20], Bloom's taxonomy [21], inductive vs. deductive learning [22,23] and scaffolding theory [24,25]. This design methodology is then implemented in the context of an example that compares the use of original design and redesign projects in a senior capstone design course.

2. Reference Design Methodology

We have chosen a product design methodology as a basis or starting point for formulating our methodology for designing hands-on activities. There are two reasons why we believe this is a good choice. First, development of both products and hands-on activities can be considered an "ill defined problem" in the sense that there is not an optimal unique solution. As the product design methodology shown below is based on a generic stencil for solving ill-defined problems, it qualifies as a reasonable starting point for formulating a new design methodology for hands-on activity development. Second, from a practical standpoint, many engineers are already familiar with the tools included in the product design methodology. This familiarity will flatten the learning curve for our new design methodology for hands-on activities.

A product design methodology (DM) is shown in Figure 1. This DM is explained in detail in [13,15]. As the approach shown in Figure 1 will be the foundation for the development of a DM to support hands-on content, each component is briefly explained.

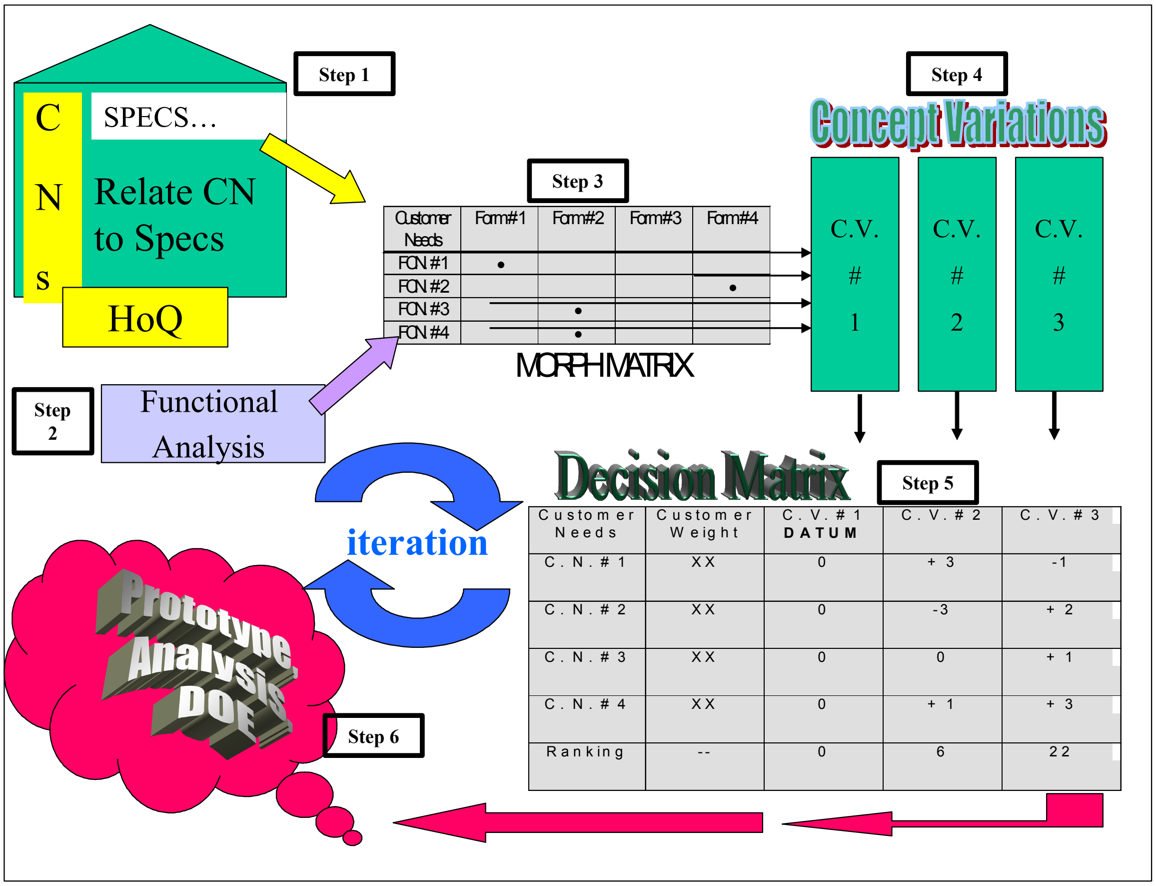


FIGURE 1 – PRODUCT DESIGN METHODOLOGY

Step 1 in the DM is represented by the graphic in the upper left-hand corner of Figure 1. "CNs" are the customer needs that must be identified in order to initiate the DM. Note that these CNs are related to the "specs" (or engineering specifications-requirements as they are sometimes called) in the House of Quality" (HoQ). The specs provide quantitative ways to measure the different CNs. As an example, consider an automobile for which one of the customer needs would be "quite ride." One of the primary specifications for this CN would be "decibels of noise at the driver's head location at 60 MPH on a paved road." This type of specification and other specs help the engineer to quantify the CNs. For more details on how the CNs and specs fit together in the chart called the House of Quality, see [13, 15].

The next design tool in Figure 1 is called functional analysis (step 2). The term "function" in this context refers to a generic (solution independent) representation of "what the product needs to do." By generic, we mean that no embodiment solution is specified. Following the automotive example above, one function that we would want in the passenger compartment would be "dissipate noise." The embodiment solution for this function might be the use of certain acoustic absorption materials in seats, ceiling or door panels. The functions in this DM are often developed through the construction of a function structure (F.S.) which tracks the flow of material, energy and signals through the system. The matrix that relates design functions to specific form or embodiment solutions is called the Morphological (Morph) Matrix (step 3). This matrix is simply a way to organize different potential embodiment solutions (formulated through brainstorming techniques or investigation of current products) for each of the functions. For more detail, again see [13, 15].

Once the Morph Matrix has been used to develop a set of potential forms for meeting the functional requirements, these form or embodiment solutions must be combined to form an actual product. If there are "N" potential form solutions described in the Morph Matrix, then there are M^N possible combinations available, where "M" is the number of functions. Many of these combinations are not achievable due to issues related to manufacturing, assembly, interface compatibility or other reasons. Taking all this into account, the designer exercises engineering expertise at this point to determine a set of potential combinations of the form solutions which are called "Concept Variants" (CV) (step 4). Next, as can be seen in the Decision Matrix (step 5) in the lower right corner of the Figure 1, these different CVs are rated against each other using the CNs (through the engineering specifications) as the basis for the rating.

Finally, the most feasible and consensus CV(s) (i.e. the CV that best meets the aggregate CNs) must be evaluated using prototyping, analysis and experimentation (step 6). In particular, it must be determined if the chosen CV will meet the specs originally set forth at the beginning of the project.

The abbreviated DM, as shown in Figure 1, is an iterative process. For example, it is possible that the analysis step will expose deficiencies in the chosen CV(s). The process could then return to the Morph Matrix to see if a different form solution(s) are available to meet the function for the deficient component. Also, it is common for the HoQ to be used later in the process then is shown in Figure 1. If it is used later in the process, it can provide a comparison between the proposed design and other currently available designs.

3. Design Methodology for Hands-On Activities

3.1 Overview

Table 1 shows the DM described above in a step-by-step manner from both the standpoint of a product development scenario and from the viewpoint of the design of a hands-on activity.

TABLE 1
DESIGN METHODOLOGY FOR PRODUCT AND HANDS-ON ACTIVITY DEVELOPMENT

STEP	Product Design Description	Hands-on Activity Design
1- CN & Specs→ HoQ	CNs focus on what a product should do; Specs quantify these CNs and the HoQ coordinates the data.	CNs clarify what the hands-on activities should accomplish. The specs measure these accomplishments and the HoQ coordinates the data.
2 & 3 - Functions and Forms → Morph Matrix	Functions are generic descriptions of what the product does (independent of form solutions). The Morph Matrix provides possible form solutions for each function.	The functions are generic educational objectives (independent of specific hands-on activities). The Morph Matrix provides potential hands-on activities for each educational objective.
4 - Combine forms → CVs	The CVs are complete product representations that combine forms to meet all functions.	The CVs are complete hands-on activities that integrate several educational objectives into a single activity.
5- Choose a CV based on CNs → Decision matrix	The Decision Matrix uses CNs and their associated weights to determine which CV best meets the aggregate CNs.	The Decision Matrix uses CNs and their associated weights to determine which CV best meets the aggregate CNs.
6- Use prototypes, analysis and experiments to validate the design	Prototypes, analysis and experiments are used to determine if the chosen CV will meet the original specs.	Determination of the level at which students' have met the engineering specifications as well as assessment of the hands-on activities against known pedagogical theory, provide assessment for the chosen CV.

3.2 Customer Needs (CNs), Engineering Specifications (Specs) in the House of Quality (HoQ)

As can be seen from the table above, the first step shows that CNs for the hands-on activity design are similar to those in a normal product development process. To be more specific, the different customer groups (stakeholders) for the hands-on activity design would be students, faculty, the university and the community. From informal survey data we have compiled the following needs and corresponding importance levels (weights) from these groups (Table 2). Note that the different customer groups have some similar needs and some different needs. The key need of "improving students' understanding" is shared by all groups and will be a dominate CN driving much of the design of the hands-on activities.

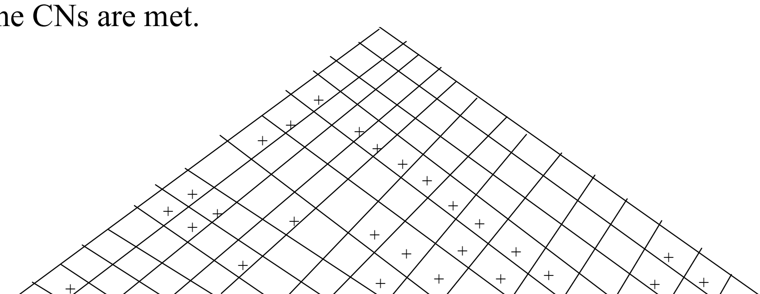
TABLE 2
CUSTOMER NEEDS ASSOCIATED WITH HANDS-ON ACTIVITY DESIGN

Customer Group	Need	Weight (sum from each group = 1.0)
1- Students	Improve our understanding	0.4
	Improve ability to solve problems	0.3
	Exciting / fun / interesting	0.2
	Real world examples	0.1
2- Professors	Improve students' understanding	0.3
	Low professor preparation time	0.3
	Low class time	0.2
	Improve student motivation	0.1
	Low cost	0.1
3- University	Improve students' learning	0.4
	Enhance university's status	0.4
	Transferable to other classes/profs & univ.	0.1
	Low cost	0.1
4- Community	Improve quality of graduates	0.7
	Enhance university's status	0.3

The specifications provide a way to quantify and therefore measure these CNs. As shown in Figure 2, the specifications include exam and homework grades, cost of the devices, time for preparation and use of the devices, in addition to many other measures. The mapping of CNs to engineering requirements (Specs) is known as the relationship matrix (body of the HoQ). The goal is to have at least one highly related requirement for every CN, assuring that each CN has a quantified measure. Without such a measure, we would not be able to definitely determine if a given concept satisfied a given CN. We have chosen to use a scale of -3 → +3 to indicate the strength of this relationship at each (row, column) in the body of the matrix. For example, the CN of "Improve our understanding" is correlated with the spec "Exam grades" by the number 3. This relationship is seen as a strong correlation because a good exam score is heavily linked to good understanding of the material. On the other hand, the CN of "Real world examples" is correlated with the spec of "Cost of hands-on devices" by the number -2. This "-2" is chosen because normally the implementation of complete real world devices would be more expensive than the use of simple parts.

The roof of a HoQ is the correlation matrix. It provides positive and negative correlations of one requirement (spec) to another. A positive correlation (+) implies that improving one spec will improve the trend in another spec. Alternatively, a negative correlation (-) implies that improving one spec will negatively impact another spec. This type of correlation represents a conflict or potential compromise situation. The goal of the designer is to break such conflicts (creatively, inventively, and through innovation) so that no compromise is necessary. Note that in this case, it appears that improvement in one spec only has a tendency to improve other specs (i.e. the roof only has "+" signs).

The last 3 rows of the HoQ contain information for each spec on importance, difficulty and whether that spec is a dependent or independent variable. The "Importance" rating comes from taking the sum of the product of each CN's weight and the matrix body value. So the importance "I" for column "j" is $I_j = \sum_{i=1}^{10} wt_i \; B_{ij}$. Where wt_i is the weight for the CN of row "i" and B_{ij} is the body value in the matrix for row "i" and column "j". Note that there are 10 CNs for this particular HoQ. The magnitude of the importance rating for each particular spec indicates its overall potential to positively affect the CNs. As can be seen in this case, the most critical specs are exam grades and performance on the Fundamentals of Engineering Exam (Importance ratings of 1.87 and 1.94 respectively). Of least importance is the amount of time it takes to do the hands-on activities in class (Importance rating of 0.07). The "Difficulty" row provides a measure of the amount of effort one estimates it would take to change this spec. This is subjectively assigned by the designer. The last row, which is labeled "Dependent/Independent" is not normally used in a HoQ as typically the design specs are independent variables (i.e. variables which the designer can specify a priori). However, in this case, it is important to indicate which of the specs are dependent and which are independent as there is a mix of the two types. For design purposes, it is most critical to focus on the independent variables as these can be directly manipulated to control how the CNs are met.



	Weight (normalized)	Exam grades	H. W. Grades	Cost of H.O. devices ($)	Class time to do H.O. Activity (min)	Time for Prof to prep H.O. (min)	End-of-course critique rating	F. E. Results in this area	Technical content removed	Publications	Grants	Adopted at other univ.	survey question on motivation	survey on exciting / fun / interestin	Problem is real world?
Improves our understanding	0.40	3	3	0	0	0	1	3	2	0	0	0	1	1	1
Improved ability to solve problems	0.12	3	3	0	0	0	0	3	2	0	0	0	1	3	1
Exciting / fun / interesting	0.08	0	1	-1	-1	0	3	0	1	0	0	0	2	2	1
Real world examples	0.04	0	0	-2	-1	-1	3	0	1	0	0	0	1	1	3
Low professor preparation time	0.09	0	0	1	0	3	0	0	-1	1	1	1	-1	-1	-1
Low class time	0.06	0	0	1	3	1	0	0	0	0	0	0	-1	-1	-1
Low cost	0.05	0	0	3	0	1	0	0	0	0	0	0	0	0	-1
Improve student motivation	0.03	3	2	0	-1	0	3	1	1	0	0	0	3	1	2
Enhances university's status	0.11	2	0	3	0	0	2	3	0	3	3	3	2	2	0
Transferable to other classes/professors/univ.	0.02	0	0	3	2	3	3	1	0	3	3	3	2	2	0
Importance		1.87	1.7	0.53	0.07	0.4	1.13	1.94	1.1	0.48	0.48	0.48	0.92	1.1	0.58
Difficulty		9	7	5	5	7	5	9	5	9	9	9	5	5	5
Dependent/Independent		Dep	Dep	Ind	Ind	Ind	Dep	Dep	Ind	Ind	Ind	Dep	Dep	Dep	Ind

FIGURE 2 – HOUSE OF QUALITY

Note that this HoQ is not based on a specific hands-on activity. The CNs and specs are generic. As we proceed to the use of the subsequent design tools, specific hands-on activities will be incorporated as examples. It is during the use of these subsequent design tools that we will generate specific information regarding the utility of original design vs. redesign type activities.

3.3 Functional Representations and Morphological Matrices

The functional description as it applies to the development of hands-on activities can be described through a set of educational objectives. As with functional descriptions in product design work, the functions must not be associated with a specific embodiment (i.e. a specific hands-on activity).

As an example, Table 3 below contains the educational objectives for the senior capstone design course at the U.S. Air Force Academy paired with the functions that come from each objective. Note that the functions take the standard "Verb + Noun" form that is commonly used in product design methodologies. The "**" designation for **Design Product** indicates that this is the primary function for the overall course.

TABLE 3 – EDUCATIONAL OBJECTIVES AND ASSOCIATED FUNCTIONS

Educational Objectives	*Function*
1. Given a statement of customer need, cadets design a system to satisfy that need based on commercial product development best practices.	** Design Product ** - Understand CNs - Implement process
2. Cadets will demonstrate the ability to effectively communicate their design.	- Communicate design
3. Cadets will demonstrate the ability to fabricate a functioning prototype of their design.	- Fabricate prototype
4. Cadets will demonstrate the ability to be effective interdisciplinary team members and leaders.	- Effectively work on teams
5. Cadet designs will comply with a realistic level of engineering codes and standards and shall include considerations such as environment, economics, manufacturability, sustainability, health and safety.	- Understand codes/standards

Below, a partial Morphological Matrix is developed from the set of functions in Table 3. As is standard practice, the Morph Matrix provides a set of specific embodiment options for each function. In this case, the "morphs" are the specific hands-on activities that meet the specified function. Table 4 is only a partial Morph Matrix due to space considerations. To facilitate the complete design process, each function must have multiple embodiment solutions developed in the Morph Matrix.

TABLE 4 – MORPHOLOGICAL MATRIX (Partial)

Function	*Embodiment (Form) Solution*
A – Understand CNs	A.1 – Have students take an ill-defined problem and determine potential customer groups for a product solution (note this is original design). Have the students survey the potential customer groups and determine CNs and associated weights from the survey data. A.2 – Have students reverse engineer products and develop an a posteriori set of CN's. A.3 – Have students study a family of similar products and propose what CNs led to different embodiment decisions. A.4 – Have students study failed products and determine what CN(s) were poorly met.
B – Fabricate prototype	B.1 – Have students take their CAD drawings and formulate prototypes using a rapid prototyping machine. B.2 – Have students develop virtual prototypes using simulation software. B.3 – Have students manufacture a functioning full-scale prototype usable for testing purposes. B.4. – Have students fabricate redesign options for existing products.

3.4 Combining Morphological Options into Concept Variants (CVs)

Concept variants (CVs) for the case of design of hands-on activities follows the same process as it does for product development work. Combinations of morphological solutions for sets of functions are packaged to form a complete system (CV) that accomplishes multiple functions. In product design work, morphological solutions may be grouped in sets to form modular designs. In that case, not all the functions for the overall product are accomplished in each CV. The same is true for design of hands-on activities. Certain hands-on activities (CVs) may be developed that accomplish only a subset of the functions. A number of these CVs can then be used successively throughout the course, eventually accomplishing all the functions. A set of CVs is shown below in Table 5 that combine different morphological options from the Morph Matrix (Table 4). Because Table 4 in only a partial Morph Matrix (i.e. not all the functions are represented), Table 5 is only a partial list of CVs (i.e. only the functions of "Understand CNs" and "Fabricate prototype" are considered).

TABLE 5 – CONCEPT VARIANTS

Embodiment Combination (from Table 3)	CV Description
CV#1 = A.1 & B.3	A full original design process beginning with CN development and proceeding through the design process (as described in Figure 1) with needed iterations to the goal of manufacturing a functioning prototype. This is the process normally used in senior capstone design courses.
CV#2 = A.2 & B.4	Products are reverse engineered to determine likely CNs as well as specs, functions and embodiment choices. Students then redesign the product by determining possibilities for improving the CNs. Their redesign options are implemented and tested against the original CNs. Assessment of the redesign quality is based on comparison of the redesigned and original product in terms of meeting CNs.
CV#3 = A.4 & B.1	Students study failed products and determine which CNs were poorly met. Solutions for these CNs are proposed and implemented in a virtual prototype using a rapid prototyping machine.
CV#4 = A.4 & B.2	This is the same option as described directly above except the prototype is implemented using simulation software.

3.5 Design Decision Matrix

It is standard practice in design decision making to use some sort of matrix to organize the decision-making process. A common form of this uses the weighted CNs as a basis for evaluating the quality of different CVs. An example of this, which evaluates the four CVs from Table 5, is shown below in Table 6. In order to quantify the evaluation of the different CVs, a datum CV is randomly chosen to which all the other CVs are compared. This example uses CV1 as the datum. For each CV (column) the question is asked, "Does the CV meet this CN (row) better or worse than the datum?." This is quantified by the use of a -3 → 3 criteria where 3 represents an evaluation that this CV meets that CN by a margin of 100% or greater. The value of 2 represents a valuation of meeting that CN better by between 50% and 100% and a valuation of 1 represents meeting that CN by a valuation of 1% - 50%. The negative valuations obviously represent the case where that CV is seen to meet that particular CN more poorly than the datum. If that CV and the datum are seen to meet that particular CN the same, a valuation of 0 is given. The body of the matrix under the datum is, by definition, all zeros as the datum is being compared to itself. The "rating" in the last row of the matrix is computed in the same way the "Importance rating" is done in the HoQ. If R is the rating, then $R_j = \sum_{i=1}^{10} wt_i \quad B_{ij}$; where wt_i is the weight for the CN of row "i" and B_{ij} is the body value in the matrix for row "i" and column "j". Again note that the limits on the summation come from the fact that we have 10 CNs in this particular case.

TABLE 6 – DECISION MATRIX USING WEIGHTED CUSTOMER NEEDS

CN (as shown in HoQ)	CN Wt	CV1-datum	CV2	CV3	CV4
Improves our understanding	0.40	0	0	-1	-1
Improved ability to solve problems	0.12	0	-1	-2	-2
Exciting / fun / interesting	0.08	0	1	0	0
Real world examples	0.04	0	3	1	1
Low professor preparation time	0.09	0	1	1	1
Low class time	0.06	0	1	1	-2
Low cost	0.05	0	1	1	1
Improve student motivation	0.03	0	-1	-2	-3
Enhances university's status	0.11	0	-2	-2	0
Transferable to other classes/profs/univ.	0.02	0	3	-1	0
RATING		**0**	**0.45**	**-0.66**	**-0.74**

From Table 6 it can be seen that CV2 has the highest rating, followed by the datum. CV3 and 4's rating are significantly below those of CV1 and CV2. The fact that CV2 is rated higher than CV1 may come as a surprising result to some as it indicates that a reverse engineering oriented hands-on project (represented by CV2) may have significant advantages over traditional original design type projects (represented by the datum CV1).

3.6 Assessment and Iteration

Based on the decision matrix results, we will choose to assess both CV1 and CV2. Assessment of these CVs proceeds in much the same way it would for a chosen CV from a product design process; the CVs are "tested" to determine how they compare to the previously stated specifications. In the example case developed in this paper, this would involve revisiting the specs shown in the HoQ in Figure 2. For example the hands-on activities proposed in CV1 and CV2 would be carried out and exam and homework scores would be kept and measured against a control group who did not use the hands-on activities. Data related to the independent specs would also be evaluated. For example, the cost of the hands-on activity and the amount of time it took to perform the activity in class would be recorded.

As an additional measure of assessment, the CVs can be rated against known pedagogical and learning styles theories. This is accomplished as shown below in Table 7. Background on each of the learning styles and pedagogical theories we have dealt with is given in the appendix.

In Table 7 we have followed the same rating scale used in the body of the HoQ varying from +3 to -3. The "Correlation Ranking" is found in the same manner as the ranking was for the decision matrix above. So $CR_j = \sum_{i=1}^{5} wt_i \quad B_{ij}$ where CR_j is the Correlation Ranking for column "j", wt_i is the weight assigned to that row (learning style or pedagogical theory) and B_{ij} is the rating number in the body of the matrix. The weights are determined based on a desire to rate the coverage of learning styles and the correlation with pedagogical theories evenly. Also, the 4 different pedagogical theories considered were weighted evenly. Note that both the CV1 (original design + manufacturing) and the

CV2 (Reverse engineering + redesign) options correlate well with the learning styles and pedagogical theories; scoring positive for all cases.

Some minor differences in ratings between CV1 and CV2 can be seen in the table. For example, CV2 (reverse engineering and redesign) is rated slightly higher than CV1 (original design + manufacturing) for both the Kolb's cycle and for Scaffolding Theory. In the case of the Kolb's cycle this is because the part of the cycle labeled "concrete experience" is more fully realized when you begin the process with an actual product. In the case of the Scaffolding Theory, the existence of a product to work with provides something from which to draw experience to build upon a priori.

TABLE 7
CORRELATION OF CVs WITH LEARNING STYLES AND PEDAGOGICAL THEORY

Learning styles / Pedagogical Theory	**Wt**	**CV1**	**CV2**
Engages breadth of learning styles	0.50	3	3
Kolb's Cycle	0.125	2	3
Bloom's Taxonomy	0.125	3	2
Scaffolding Theory	0.125	1	3
Inductive / Deductive	0.125	3	3
Correlation Ranking		**2.625**	**2.875**

4. Conclusion

This paper presents a structured design methodology, based on a well-known product design approach, for use in the development of hands-on activities for design-oriented courses. Design tools such as Customer Needs Analysis, generation of Specifications, correlation between Customer Needs and Specifications in the House of Quality, Functional Decomposition, Morphological Matrices, Construction of Concept Variants, Decision Matrices for evaluation of Concept Variants and Analysis based on evaluation of Specifications and pedagogical theories are all incorporated.

As an example, different hands-on activities for use in the senior capstone design course at the U.S. Air Force Academy are evaluated using this design methodology. The insight from this study indicates that hands-on activities of the sort normally used in a capstone course (an original design project including embodiment) work well in helping to achieve the educational objectives. In addition, use of reverse engineering and redesign is shown to have significant benefit and is shown in many ways to better meet the customer needs. Based on this evidence, design professors may wish to consider integrating both an original and a redesign experience into their courses as has been documented in [13]. It should be noted that the choice of specs and the weights assigned to different CNs have a significant impact on the final outcome of this process. Therefore, the outcomes from our particular example are not necessarily globally applicable to other institutions. However, the process of using a proven design method to logically and systematically arrive at an outcome based on the unique weighted CNs and specs for that institution, we believe to be globally applicable.

In the future, we plan to perform a comprehensive study of hands-on approaches/experiences to include documenting, categorizing, dissecting, and analyzing the different approaches. This work may be based exclusively on a literature review or it may also include empirical work. During this extensive literature review, we would hope to extract principles and guidelines of successful hands-on approaches and artifacts. Also, we hope to be able to generalize this design methodology to include concept generation of hands-on activities across Mechanical Engineering, engineering as a whole, natural science, and even liberal arts; demonstrating more general applicability of our methods. Hopefully, as we expand applicability of these techniques, we will be able to answer questions concerning the robustness of our hands-on approaches. This will help us to develop methods that are insensitive to student personality types, learning styles, cultural background and gender.

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7. Appendix - Learning Styles & Pedagogical Theory Overview

We selected three methods to categorize student's learning styles: (1) MBTI, (2) VARK, and (3) 6 Hats and four models of the learning process: (1) Kolb, (2) Bloom's Taxonomy, (3) Scaffolding, and (4) Inductive / Deductive flows. Each of these is described briefly below. Although these educational or psychological theories are, of course, not our original work, there are aspects of ***the use*** of these in our educational innovations that are original. These include 1) the particular mix of three methods to categorize student's learning styles and four models of the learning process which gives our work a more balanced foundation than may be possible if one bases their approach on one or two theories only , 2) our work showing correlation between MBTI and particular learning propensities is original.

7.1 MBTI Overview

The MBTI type indicator includes four categories of preference (Table A-1) [17-19] Although MBTI categorization is well-established, its use as an indicator of the way people learn is far less common. The second of the four categories provides insight into how a person processes information. Those who prefer to use their five senses to process the information (sensors) are contrasted with those who view the intake of information in light of either its place in an overarching theory or its future use (intuitors). This sensor vs. intuitor category is seen by most researchers to be the most important of the four categories in terms of implications for education [7,8,15].

TABLE A-1: Overview of MBTI

Manner in Which a Person Interacts With Others			
E	Focuses outwardly. Gains energy from others.	Focuses inwardly. Gains energy from cognition	**I**
EXTROVERSION		**INTROVERSION**	
Manner in Which a Person Processes Information			
S	Focus is on the five senses and experience.	Focus is on possibilities, use, big picture.	**N**
SENSING		**INTUITION**	
Manner in Which a Person Evaluates Information			
T	Focuses on objective facts and causes & effect.	Focuses on subjective meaning and values.	**F**
THINKING		**FEELING**	
Manner in Which a Person Comes to Conclusions			
J	Focus is on timely, planned decisions.	Focus on process oriented decision-making.	**P**
JUDGEMENT		**PERCEPTION**	

7.2 VARK Overview

The present work also builds on student learning preferences as obtained from an instrument called the VARK Catalyst. Rather than being a diagnostic tool for determining a student's learning preference, the VARK test serves as a catalyst for reflection by the student [2]. The student takes a simple 13-question test that is aimed at discovering how they prefer to receive and process information.

After taking the test, the student receives a "preference score" for each of four areas. The first area is Visual (V). This area indicates how much the student prefers to receive information from depictions "of information in charts, graphs, flow charts, and all the symbolic arrows, circles, hierarchies, and other devices that instructors use to represent what could have been presented in words." The second area is Aural (A). This area indicates the student's preference for hearing information. The third area is Read/Write (R). This area shows a student's preference for information displayed as words. The fourth area is Kinesthetic (K). In short, this area indicates a student's preference for "learning by doing." By definition, the "K" area refers to a student's "perceptual preference related to the use of experience and practice (simulated or real)." The scoring of the test allows for the student to show mild, moderate, or strong learning preferences for each of the four areas.

7.3 6-Hats Overview

In the original 6-Hats work [26], six communication styles/roles were identified. Each style/role is associated with a certain color. When a person is using that particular style/role, they are said to be wearing that "hat". The current work focuses on the use of these 6 styles/roles in a different manner than the original work. The idea in the present work is simply that each individual has established patterns of communication which can be identified using the 6-Hats categories. Once these preferred communication styles/roles are identified, they may be used in a design team formulation strategy (TFS) to both balance communication styles/roles as well as to ensure certain styles/roles are present. In addition, the communication styles/roles (as identified by 6-Hats) can be used to facilitate effective group communication by identifying strengths and potential weaknesses and common conflicts that arise between certain "hats". Table A-2 shows the 6 different hats and associated characteristics.

Table A-2: Overview of 6-Hats Communication Styles/Roles

White Hat •I focus on objective facts. •I enter into a discussion without preconceived ideas •I seek to know the statistical evidence concerning a decision •I try to think totally objectively about a situation •I seek to differentiate between facts and opinions •I am more interested in facts than opinions	**Red Hat** •My feelings sway my decisions •I have good intuition •My personal opinions/emotions play a significant role in my decision making process •I am suspicious of other people's decision making process
Yellow Hat •I usually see the positive side of things •I can often see the good parts of even a bad idea •I am usually optimistic that a new idea will work •I believe that most new ideas have significant value •I usually "look on the bright side" of a problem •My comments are usually positive and constructive	**Black Hat** •I can quickly see why an idea will not work •I often can tell an idea will not work by judging from past experience •I like to play the "devil's advocate" •I can readily detect poor logic in someone's argument •I am often pessimistic of others ideas
Green Hat •I am creative •I often generate new ways of thinking about a problem •I easily think "outside of the box" •I am constantly thinking of alternatives •I am not likely to settle for the "status quo" •I can easily generate new concepts	**Blue Hat** •I like to lead the problem solving process •I tend to think as much about the problem solving process as the problem itself •I focus on the big picture, summarize and draw conclusions •I find myself trying to keep the group focused •I often help the group clearly define the problem

7.4 Kolb Cycle Overview

The Kolb model describes an entire cycle around which a learning experience progresses [20]. The goal, therefore, is to structure learning activities that will proceed completely around this cycle, providing the maximum opportunity for full comprehension. This model has been used extensively to evaluate and enhance teaching in engineering [27,28]. The cycle is shown in Figure A-1.

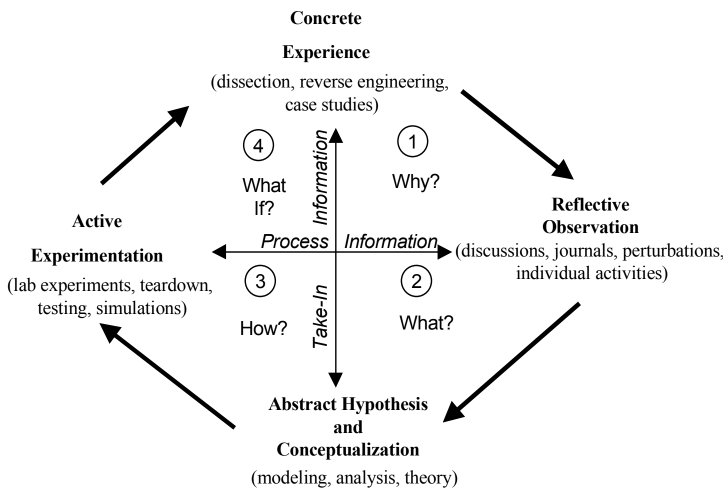

Figure A.1 – Kolb Cycle

7.5 Bloom's Taxonomy Overview

Bloom's taxonomy gives 6 levels at which learning can occur [21] (Table A-3). In general, a higher level corresponds to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher education toward the higher levels

TABLE A.3 – Overview of Bloom's Taxonomy

Level	**Name: Description**
1	Knowledge: List or recite
2	Comprehension: Explain or paraphrase
3	Application: Calculate, solve, determine or apply
4	Analysis: Compare, contrast, classify, categorize, derive, model
5	Synthesis: Create, invent, predict, construct, design, imagine, improve, produce, propose
6	Evaluation: Judge, select, decide, critique, justify, verify, debate, assess, recommend

7.6 Scaffolding and Inductive/Deductive Learning Overview

The term "scaffolding" encompasses the idea that new knowledge is best assimilated when it is linked to previous experience [24, 25]. A well-planned flow of material that builds on itself and integrates real-world examples obviously helps provide this "scaffold" for learning. The terms "deductive learning" or "inductive learning" refer to learning from general to specific or visa-versa. For example, showing the theory followed by working an example is a form of a deductive process. Most courses use deductive approaches. The literature argues that this approach is not always appropriate; stating that a mix of the two approaches provides the best learning environment.

8. Biographical Information

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