Beyond Problem Solving to Creating Value: A Priority for Engineering Educators

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Introduction

The increasing complexity of the challenges facing our society and world suggests that engineering graduates must be outstanding problem solvers, designers, and value creators in a variety of business and social settings. The solutions, designs, and systems created must solve technical problems and provide benefit to a variety of stakeholders who may have broad interests in financial, social, and environmental outcomes.

Engineering education often focuses on the quantitative skills of problem solving yet solutions to many of the most challenging problems require higher level design, entrepreneurial mindset, and value creation skills. The opportunity to create value, or to fail to, occurs in many settings with engineers commonly called upon to create value in design settings. While being a good designer is a hallmark trait of an engineer, current approaches to teaching and practicing design need improvement because a high percentage of products and services introduced to the marketplace fail to find success. An engineering education with emphasis on employing an entrepreneurial mindset would improve the odds of success.

The 3 C's – Curiosity, Connections, and Creating Value have been identified as the core elements of an entrepreneurial mindset. 'Creating value' is a critical theme and this paper takes a step in exploring recent developments that help to define and clarify the mindset and skillset that undergraduate engineering students should have to achieve it.

Applying methods from systems engineering, this work extends the idea of developing a product to developing a successful solution within a system. That system includes stakeholders, features, and a series of views representing the designed system or product. It is shown that these results are highly complementary to existing conceptions of 'creating value' as part of the 3 C's. Tools and views are presented for classroom use to support the creating value objective through studies of successful and unsuccessful products. Results from a first run of a class exploring these new approaches along with student assessment data are provided.

Importance of but Lack of Success at Creating Value

If successful products or new ventures are measures of creating value, then success is difficult to achieve in both cases. The literature suggests that only 60% of new products[1] find success and only 50% of new ventures survive for five years[2,3]. These poor levels of success indicate that while value creation is a top priority for all organizations to survive and thrive, new approaches are needed to achieve success more consistently. These results also inform engineering educators of the importance of instilling the mindset and skillset of creating value in our graduates such that they can be value creators in the workplace of the future.

Objectives of this study

Several objectives for this paper were identified at the outset of this work. A general objective is to establish a more comprehensive understanding of the mindset and skillset of the 'creating value' theme in the 3 C's. Additional objectives for the paper include:

- surveying the literature and summarizing current concepts of 'value' in general and the 'creating value' themes,
- highlighting the importance of creating value in light of success often being elusive in new product introductions,
- identifying new approaches, tools, and views from disparate sources that illustrate that creating value occurs at multiple levels including the enterprise level and the product design level,
- synthesizing this new information to propose more comprehensive conception of creating value as part of the 3 C's,
- presenting new tools/views to support creating value that may be used by educators,
- applying these views identified to case examples of the Keurig Coffee and Kold examples to illustrate how value creation occurs or fails to occur, and
- reporting on a first offering of a new course with student assessment data.

Concepts of Value

A vast body of literature exists on the topic of 'value'. A common economic concept of value is benefit in proportion to cost[4,5]. While financial measures are often assumed, a broader definition of value has additional dimensions including financial, environmental, cultural, etc. This broader definition is connected to the concept of preference by and individual or societal group. Some products find or fail to find success based on cultural perceptions. The Lucky Iron Fish is a small iron cooking device intended to prevent iron deficiency and anemia. Unsuccessful at first, it found success when it was shaped in the form of a culturally desirable shape of a fish[6]. This example underscores that value is ultimately in the eye of the beholder(s), and includes perceptions founded within cultural norms and other individual preferences. Another example includes the notion of value within behavioral economics, a field founded on contextualized economic preferences.

Other common concepts of value is that it is relative, perceived by the user or customer, and that it may be situational, seasonal, or temporal[7]. The perceived value of a snow shovel or bottle of water would be vastly different considering a seasonal viewpoint of summer or wintertime.

Results from the field of systems engineering provide additional insights into system modeling and value[8,9,10]. Key findings here include that:

- Value is not inherent in a product or system but is perceived by users and stakeholders. More features do not mean more value.
- Value is created when the right alignment of stakeholders and features occurs. Products may fail because they do not offer basic features that stakeholders find attractive or they have too many features leading to complexity and 'feature fatigue'[11,12].
- Value is a concept of choice or selection. A product or system demonstrates value if it is selected above other alternatives. This aligns with the Christensen concept that consumers 'hire' a product to perform a job[13].

Concepts of 'Creating Value'

The 3 C's of an entrepreneurial mindset include creativity, connections, and creating value. The literature related to the creating value theme provides detail of 'identifying opportunity', 'identify real opportunity', 'design iteration and prototyping' and 'impact' [14,15]. All suggest that creating value can occur at multiple levels including the venture, enterprise or organizational level, in products and design activities, and even the social and environmental levels[16]. The following sections provide an expanded examination of these different levels including comparisons to popular works on innovation and value.

At a venture, enterprise, or unit level, value can be created through incremental or major changes to the offerings or business model. Design thinking has presented the concept of value resulting from the balance of desirability, feasibility, and viability[17]. Design thinking is a human centered, empathetic approach involving divergent and convergent thinking resulting in solutions more aligned with user needs. Closely aligned with the 'desirable, feasible, and viable' themes is a representation of innovation in an entrepreneurial or existing organization as shown in Figure 1.

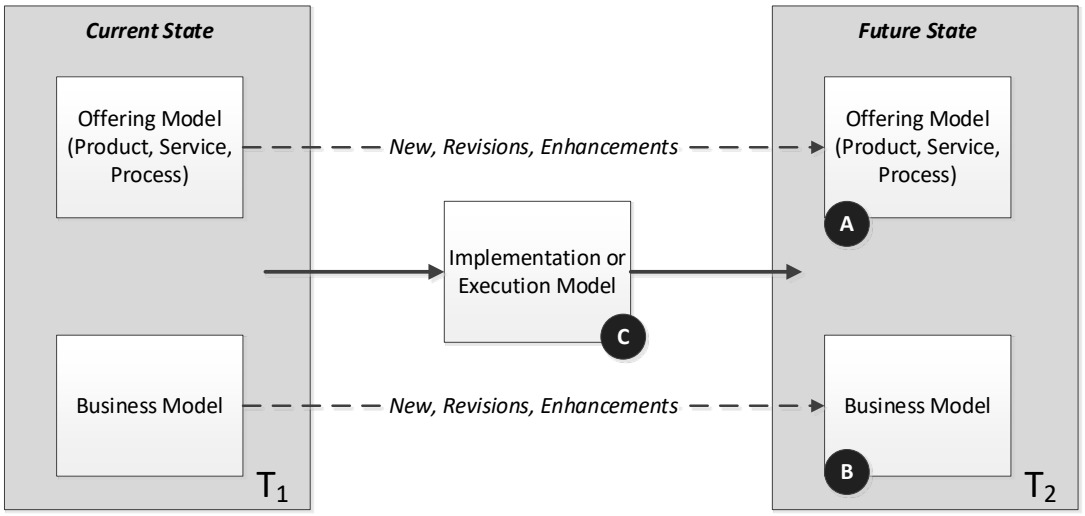

Figure 1 – Three Models for Enterprise Innovation and Transformation[19]

Three components are necessary to develop and implement successful offerings supported by a sustainable organization (T2) and thus capture value in a marketplace. The three components are a model of the product offering (A), a business model (B), and an execution model (C) to build or transform the organization from T1 to T2. Each of the three elements have been represented with a canvas, the most notable being the Business Model Canvas[18]. The implementation or execution model (represented by an IVP canvas) includes an internal value proposition of why is the organization pursuing the activity along with all of the actions that the organization must do to develop or transform itself to reach the new state T2[19]. These actions may include production, marketing, and sales support activities. The design models (represented by a design canvas) are based on systems engineering views of the key items of information necessary to represent the behavior, structure, components and value aspects of the product or system[20]. Figure 1 suggests that it is necessary to align all three models to have a credible chance to create and capture value in a sustainable manner. If only two of the three have been considered, the chance of success and creating value is diminished. Both the views themselves[22] and design canvases[21] have been

presented. Figure 1 is valuable on its own and aligned with the design thinking approach, but further analysis and detail are available in deeper exploration of the three canvases.

Taking a systems view, some might consider the three models in Figure 1 as subcomponents of one larger enterprise system as it goes through the normal course of business or that the product is part of the business model. However, viewing them as three separate ones with separate canvases is a teachable concept readily grasped by students.

Concepts of 'Creating Value' in Design

In this section, we focus on the opportunities to create value in product design activities. Being a good designer is a hallmark trait of an engineer and design curriculum is an integral component of engineering education programs. As noted above, success in product design is elusive as 40% or more of products introduced to the marketplace fail to find success[1].

Concepts from systems engineering have been applied in developing a series of value-connected views (tables and diagrams) that have been applied in design courses at all levels[22]. The views are based upon a comprehensive metamodel[23] that identifies items of information necessary to completely characterize the behavior, structure, components, and value in a system. The metamodel has been applied to all types of natural and human made systems. A unique characteristic of this work is the proposition that value in a system is expressed by system features and the stakeholder perceptions of them[10]. Pursuing this concept further, two views have been developed to encourage identification and alignment of stakeholders and features and also enable comparison of competing solutions. These two views have been applied to the analysis of a Keurig coffee maker in the following example.

The Keurig coffee machine was introduced in 1998 as a single cup coffee making system for the office market. Machines for the home market were introduced in 2004. The coffee brewers and K-Cup pods have found success as an innovative alternative to traditional dip style makers. A Keurig coffee maker is a 'system to provide coffee' and it will be compared to a drip style maker and to Starbucks.

The first view is shown in Figure 2. The stakeholder/features table shows three stakeholders at the top, the coffee drinker, the buyer of the machine, and the maintainer who cleans up the machine. On the left, several features and attributes are identified including taste, temperature, and time to prepare and clean up. The columns of the table shows the stakeholder preferences for the various attributes. Listing all relevant stakeholders is critical to in turn identify important features that may determine the ultimate success of the design. If features are listed that are not important to any stakeholders, they should be evaluated for removal.

The second view in Figure 3 compares multiple design options to the same features identified in the stakeholder/feature table. In this case, the traditional drip coffee maker (D1) is chosen as the benchmark with a score of zero for comparison. The scores in each row indicate how well each design option (D2, D3) provides or implements each feature relative to the D1 benchmark. A design option that compares more favorably on many important features would likely be chosen more often than the competing ones. Overall scores can be calculated here but this must be done with care to consider the appropriateness of equal or other weighting schemes.

System to Provide Coffee		Stakeholders from User to Provider		
		Drinker	Buyer	Maintainer
	Stakeholder Priority	High	High	Medium
Feature Name	Feature Attribute	Feature Priority	Feature Priority	Feature Priority
Time to deliver coffee	Time	E	E	
Time to clean up	Time		E	D
Coffee taste	Survey	D	E	
Coffee temperature	Degrees	E		
Coffee variety	Number of types	D		
Affordable	Cost/unit		E	
	Cost/serving	E		
Durable	Time		E	E

E=Expected, D=Delighters, 0 (or blank)= Don't Care, 1= 1 Dimensional, ↓= Detractor

Figure 2 – Keurig Coffee Stakeholder/Feature Table

The Keurig Coffee product compares favorably on several important features of time to deliver, time to clean up, and taste. From this analysis, one could conclude that the Keurig Coffee with several favorable feature comparisons could have the possibility of competing successfully with the options considered.

System to Provide Coffee	--					-					0					+					++	D1	D2	D3
Relative Value	-1	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	-0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1			
Feature Name																								
Time to deliver coffee	D3										D1					D2							0.5	-1
Time to clean up											D1					D2					D3		0.5	1
Coffee taste											D1					D2			D3				0.5	0.8
Coffee temperature										D1, D2, D3													0	0
Coffee variety											D1					D2					D3		0.5	1
Affordable - C/U						D2					D1										D3		-0.5	1
Affordable - C/S	D3					D2					D1												-0.5	-1
Durable									D2		D1		D3										-0.2	0.2
																					Scores	0	0.8	2

Design	Detail
D1	Traditional Coffee Maker
D2	Keurig Coffee Maker
D3	Starbucks Coffee

Figure 3 – Keurig Coffee Features/Designs Table

This two-step approach provides an effective way to introduce the key concepts and capture the important information to assess and compare value among various design options. Students focus on identifying key stakeholders, relevant features, stakeholder perceptions of features, and relative comparison of multiple design options.

Recent work from Ulwick[25,26] is also systems based and supportive of the creating value objective. This work supports the 'jobs to be done' (JTBD) theme[13] and includes key concepts of the job, outcomes, over/underserved outcomes, and opportunity scores. The 'job' is a functional description of what a product does. The job of a coffee machine is to 'provide coffee'. This approach is beneficial in identifying multiple solutions that may perform the job or in expanding the scope and combine multiple jobs within a single product. Outcomes are equivalent to features and rather than ranking outcomes, opportunity scores of importance and satisfaction are determined for each one through customer surveys. The prime or underserved opportunities correspond to outcomes which customers rank as highly important but where they are unsatisfied with current solutions. While commonly applied in marketing studies, these concepts are also valuable in product design as well.

A Proposed Value Creation Mindset and Skillset

The concepts from the previous sections have been synthesized to develop a more comprehensive and detailed description of 'creating value'. Table 1 below show the commonly cited outcomes in columns one and two with the proposed expanded skills and tools as a result of this work. The concepts of 'opportunity and impact' can be expanded into more detail including improving performance, expanding the scope, identifying critical stakeholders and features, and developing product, business, and execution models. A more detailed list of the elements of a 'value creation' mindset in an engineering education entrepreneurial context includes:

1. Value is a relative concept and is illustrated through selection or choice.
2. Creating and capturing value at the enterprise or organizational level can be illustrated in the completeness and alignment of product, business, and execution models. (customer desirability, technically feasible, business viability, organizationally implementable)
3. The value of a product or offering can be studied by a. identifying important stakeholders and features and b. developing a product or offering to perform and exhibit the important features identified.
4. Products and systems are successful when they provide capabilities and characteristics that a significant number of stakeholders find attractive and choose over competing options.

Proposed skillset tools or views are also listed in column four of Table 1. These visual tools or views capture important mindset information and then enable assessing the completeness and alignment of the information collected. The structure of the views encourages students to identify information to "fill in the blanks" and in doing so, are collecting the important items of mindset information. The critical few skillset tools include the stakeholder/feature table, features/designs table, domain diagram, design canvas, business model canvas, IVP canvas, job map, and opportunity score table. Brief examples of the stakeholder/feature and features/designs tables are provided in this paper and more detailed examples of other tools will be provided in subsequent work.

Skill Category	Complementary Skills	Expanded Skills	Tool or View
Opportunity	Identify an opportunity	• Improve the performance of a product or job performed. • Expand the scope of a product or job. • Identify key, relevant stakeholders. • Determine over and underserved customer needs.	• Domain Diagram • Stakeholder/Features Table • Job Map • Opportunity Score Table
	Investigate the market	• Determine over and underserved customer needs. • Define a market as a group of users and the job they want to be done. • Determine market size and characteristics.	• Opportunity Score Table • Business Model Canvas
	Evaluate customer value, societal benefits, and economic viability	• Assess product value relative to competing options. • Identify environmental, societal, and cultural factors as features. • Assess economic viability by comparing to competing options. • Develop conceptual product, business, and execution models. • Diagnose unsuccessful product cases.	• Stakeholder/Features Table • Features/Designs Table • Business Model Canvas • Design Canvas • IVP (Innovation Value Proposition) Canvas
	Test concepts quickly via customer engagement	• Build models rapidly to assess completeness and alignment of concepts.	• Design Canvas • Business Model Canvas • IVP Canvas
	Assess policy and regulatory issues	• Identify policy and regulatory issues as features.	• Stakeholder/Feature Table
Impact	Validate market interests	• Identify key market assumptions in models	
	Identify supply chains and distribution channels	• Explore and assess execution issues. • Explore and assess operational issues.	• IVP Canvas • Business Model Canvas
	Protect intellectual property		
	New	• Identify challenges and risks to implementation.	• IVP Canvas • Business Model Canvas

Table 1 - Creating Value skills (Columns 1 and 2) from refs 14,15
with proposed expanded skills and tools (Columns 3 and 4)

A New Course in Design and Creating Value

A new course offered recently incorporated many of the concepts outlined in this paper. The course examined design and value creation in a multidisciplinary way focused on performing design in a market/social context and creating value for the stakeholders involved.

A brief list of learning objectives for the course are listed below.

1. Describe various aspects of value provided by engineered systems.
2. Describe the importance of stakeholders and features in defining value in design.
3. Describe fundamental concepts and steps in product design and realization.
4. Describe key items of information needed to describe behavior, structure, design, and value in a system.
5. Develop three models or canvases that impact the achievement of a successful product or system.
6. Develop basic systems views, explore multiple candidate solutions, and select a recommended solution that provides value to stakeholders.
7. Apply views to develop design proposals for new products and to diagnose case studies.

Case study analysis was a frequent and popular aspect of the course. The example of the successful Keurig Coffee machine was provided in the previous section. Keurig also introduced the unsuccessful Keurig Kold and this case was examined in the class using the views presented in this paper.

Stakeholder/Feature in Figure 4 is similar to coffee example with taste, temperature, and time being key features. Here one of the competing options is a soft drink in a can. In Figure 5, the product scores unfavorably on many important features of time to deliver, time to clean up, affordable and the same on taste and temperature. From this analysis, one could conclude that the Keurig Kold with few favorable feature comparisons might have difficulty finding success with this competing option also available.

System to Provide Soft Drinks		Stakeholders from User to Provider		
		Drinker	Buyer	Maintainer
	Stakeholder Priority	High	High	Medium
Feature Name	Feature Attribute	Feature Priority	Feature Priority	Feature Priority
Time to deliver drink	Time	E	E	
Time to clean up	Time		E	D
Drink taste	Survey	D	E	
Drink temperature	degrees	E		
Drink variety	Number of types	D		
Affordable	Cost/unit		E	
	Cost/serving	E		
Durable	Time		E	E
Desirability of Soft Drinks	Survey	D, ↓	↓	

E=Expected, D=Delighters, 0 (or blank)= Don't Care, 1= 1 Dimensional, ↓= Detractor

Figure 4 – Keurig Kold Stakeholder/Feature Table

System to Provide Soft Drink	--					-					0					+					++
Relative Value	-1	-0.9	-0.8	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	-0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Feature Name																					
Time to deliver drink						D2					D1										
Time to clean up						D2					D1										
Drink taste											D1	D2									
Drink temperature											D1	D2									
Drink variety								D2			D1										
Affordable $/unit	D2										D1										
Affordable $/serving								D2			D1										
Durable									D2		D1										
Desirability of Soft Drinks											D1	D2									
																				Scores	

	D1	D2	D3
		-0.5	
		-0.5	
		0.1	
		0.1	
		-0.3	
		-1	
		-0.3	
		-0.2	
		0	
	0	-2.6	

Design	Detail
D1	Soft Drink in Can
D2	Keurig Kold
D3	

Figure 5 - Keurig Kold Feature/Designs Table

Other case studies analyzed in the course include Exubera inhalable insulin, NeoNurture infant incubator, IDEO shopping cart, PlayPump, and the Lucky Iron Fish. In all cases, the views developed revealed interesting and teachable insights into stakeholders and features and suggested either success or failure in each case.

Aspects of this course and introducing these new concepts that were successful include:

- Undergraduate students are capable learning an applying the various design views in the context of a quarter long course,
- The views are useful for directing the students to collecting the relevant information of a design problem,
- Case studies of successful/unsuccessful products were very successful in illustrating the application and benefit of the proposed approaches, and
- Of all the views and concepts presented, identification of stakeholders and features was the most important.

Aspects of introducing these new concepts that were not as successful include:

- Although students could learn and apply the tools and views in a quarter long course, a significant amount of time was needed to do this,
- Extending this result, too many views were introduced and this number needs to be reduced to a more manageable 3-5 views (rather than 8-9),
- Students were able to develop a variety of design views but were less successful at verifying the data and information that they had collected,
- Students were less successful at using the views to develop and synthesize multiple design concepts,
- Multiple aspects of value were introduced such as financial, environmental, and social but students were less successful at appreciating these multiple dimensions, and
- The course only focused on creating value at the product/system level and value at the enterprise level was not covered. It would be challenging to cover both in detail in a one term course.

Table 2 summarizes student assessment data from the class (n=14) with "top 2" percentages listed in the right column. With a class focus on case studies, a highest score of 100% was reported for "the design views are useful for analyzing and diagnosing product failure case studies". High scores were also reported for a. "the design views are useful in developing a design that provides value to multiple stakeholders" with a top 2 score of 86% - and b. "we looked at several views … and these views helped me include perspectives of multiple stakeholders including the environment and culture" with a top 2 score of 93%. While these are positive scores and feedback, additional assessment is needed to fully assess the benefits of these approaches.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Top 2
Discussing design processes and design information as separate topics helped me to develop a more complete understanding of design	0	0	1	11	2	**93%**
The design views are useful in:						
Analyzing and diagnosing product failure case studies	0	0	0	11	3	**100%**
Developing a design for a news system as experienced in the term project	0	1	2	6	5	**79%**
Developing a design that provides value to multiple stakeholders	0	0	2	6	6	**86%**
Considering multiple dimensions of value such as financial, environmental, and social	0	1	5	7	1	**57%**
Thinking about this class and previous design classes, the approach and views presented in this class:						
Are easier to develop	0	0	4	8	2	**71%**
Contain more information	0	1	4	3	6	**64%**
Help me to develop better designs	0	0	3	10	1	**79%**
We looked at several views including Stakeholder/Feature Table, Domain Diagram, Functional Architecture, Physical Architecture, and Features/Designs Table. These views helped me:						
Collect relevant information for a design problem	0	0	2	8	4	**86%**
Identify gaps in information collected	0	0	5	6	3	**64%**
Develop multiple candidate designs	0	1	1	8	4	**86%**
Include perspectives of multiple stakeholders including the environment and culture	0	0	1	8	5	**93%**
Compare and assess the likely success of designs	0	0	4	9	1	**71%**

Table 2 – Student assessment data from design class (N=14)

Conclusions and Future Work

This paper has explored the important topic of 'creating value' and has offered expanded conceptions of the mindset and skillset of value creation. Concepts from the fields of design, entrepreneurship, and systems engineering have been applied in this work. It is noted that opportunities to create value occur at the venture/enterprise level or at the product/system level. The proposed concepts align well with popular works in design and innovation.

It is hoped that this paper will inspire additional work on this important topic. Topics suggested for more detailed study include definitions and metrics to assess value creation, refinement of the various views proposed, development of classroom materials to introduce these concepts, and more comprehensive assessment of classroom results.

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