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Development of a Design Canvas with Application to First-Year and Capstone Design Courses

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Development of a Design Canvas with Application to First-Year and Capstone Design Courses

The adoption of canvas tools in entrepreneurship and design education is increasing. The Business Model Canvas (BMC), perhaps one of the best-known canvas tools, is the key element of the Lean LaunchPad methodology (Blank, 2013) – a widely utilized approach to business model development. Importantly, using canvases like the BMC supports student learning through a data-driven and iterative process that actively engages students. Another benefit of the canvas approach in an educational setting is they can be used in a preliminary or conceptual design phase, where students can begin to identify and make associations among the key themes of the more complete underlying models used to represent the system being envisioned and developed. These benefits have led to the development of many new canvases with some expressly created for design courses in engineering education settings.

A model-based approach for understanding and developing canvases has recently been presented (Tranquillo et al., 2016). This approach notes that canvases are high level representations of underlying complex systems. As alluded to above, these complex systems can be business models, but they can also be products, devices, or manufacturing and supply systems. Briefly, a canvas is constructed by selecting interrelated elements of system models that represent the underlying real systems. Through this representation, canvases can be developed by identifying and illustrating 1) the underlying system being conceptualized, 2) the model used to represent the system, and 3) the themes selected from the model to be placed on the canvas.

Despite these benefits and new approaches to developing canvases, many of the canvases currently being used are better suited for use by sophisticated users and may be too complex for students in undergraduate design courses. To address this complexity, a process for developing a canvas for first-year or undergraduate design courses is illustrated in this paper. The process enables an instructor to develop a canvas for *their course* by examining the learning objectives for the course and identifying the key themes of their learning system and content. Finally, we utilize this process to propose canvases suitable for undergraduate courses from first-year and capstone design.

<u>Opportunities in Design and Entrepreneurship Education</u>

In today's design and technical entrepreneurship courses, students are commonly asked to envision and design a product offering along with a business model. In many cases, the product, device, or system being developed is a complex technical system that is being developed for a business setting impacted by competition, regulation, and social complexities. Dym et al., in their classic work on design teaching and learning, note that "design is hard to learn and harder still to teach" (Dym et al., 2005). Importantly, they make distinctions between design outcomes, representations of information (models), and design processes followed; highlighting the need for an authentic assessment of all three. While the Business Model Canvas is becoming a widely accepted tool for business model conceptualization, this work extends the canvas landscape to explore an educational tool and approach for the design of a product offering.

To frame our approach, Crismond and Adams (2012) provide insights into the traits of designers and compares the traits of student designers in relation to more successful and informed designers. Two common themes are evident in Table 1 – a) students don't collect enough or the right information before they start designing and b) students don't follow a systematic and interative process when engaging in design.

Design Approach	**Student Designer**	**Informed Designer**
Understand the Challenge	Treat design as a *straightforward problem* and *prematurely attempt to solve it*	Explore, *comprehend, and frame* the design problem
Build Knowledge	Skip research and *immediately pose solutions*	*Research* the problem, system operation, and prior solutions
Generate Ideas	Fix on one or a few ideas	*Explore many ideas through brainstorming and divergent thinking*
Weigh Options	Make decisions *without considering all options* or favor some options	Use text and graphics to *weigh benefits and tradeoffs* of ideas
Revise/Iterate	Design in a *haphazard manner* or do steps once in a *linear order*	Ideas are *revised based on feedback through multiple cycles*

Table 1 – Comparison of Student vs. Informed Designer Traits with added emphasis (Crismond and Adams, 2012)

Other works highlight the importance of a needs-based approach and discernment regarding product features when designing successful products. For example, Ulwick (2011) concludes that starting with a "needs first" approach (identifying customer and stakeholder needs) is superior to an "ideas first" approach (identifying a number of creative/innovative ideas) when developing successful new products. Related to features, Hamilton et al. (2017) note that some product features attract new customers while others retain existing customers. Rust et al. (2006) also report that consumers believe they want feature-loaded offerings when considering a purchase; however, once they start using their purchase, they suffer from "feature fatigue." That is, consumers get overwhelmed by complexity and annoyed by features they don't need. These authors suggest that designers should consider offering a wider assortment of simpler products instead of all-purpose, feature-rich products.

Beyond these consideration, Simoni et al. (2016) recently presented a systems engineering approach for undergraduate design education. Their approach applies established systems modeling frameworks in an effort to develop a design framework that has been used successfully in first year to capstone design courses. An important finding of their systems framework is the realization that a common set of models or views can be applied to a wide variety of design problems, making the approach easier for students to learn and faculty to teach and assess.

Moreover, the canvas approach can provide benefits for both the instructor and student, extending those reported for the model-based approach. For example, there are several benefits for the instructor. The canvas can be beneficial as a teaching framework or high-level dashboard for design. Through the customizable approach described in this paper, the instructor can develop a canvas to suit their course needs to present as much of the design process as they choose to suit the experience level of student designers. The canvas supports multiple teaching approaches. The instructor can guide students in using the canvas either in a more rigid way indicating what steps to follow or allowing students to explore and follow their own path to collect and synthesize design information.

From the student perspective, interaction with a canvas encourages students to collect and categorize the information needed to develop their design. Students can be instructed to explore the comprehensiveness and alignment of information at a conceptual level before delving into more extensive design representations. In essence, students are exploring the design landscape and developing a conceptual prototype of their design before advancing on to extensive modeling and prototyping. Additionally, the canvas provides a bounded, one-page framework for approaching a design problem. The canvas suggests the instructor's high-level intent for the class or project. It enables a student team to take action to collect information with the blank areas highlighting the need for attention. As high-level information appears, it encourages association and alignment across the canvas boxes. Because no fixed process steps are explicitly encoded in the canvas, it can encourage iteration as new information is added.

Objectives of this Study

Having identified opportunities to add value in design and engineering education, we established several objectives at the outset of this work. An overarching objective was to develop a design and entrepreneurship education tool that addresses the opportunities identified above, particularly by supporting instructors ability to guide students in the shortcomings identified by Crismond and Adams in Table 1. We identified this goal based on Castellion and Markham's (2013) acknowledgement that even though design and prototyping tools afford us the ability to quickly test new designs and collect more information than ever before, some 40 percent of new products still fail to find success in the marketplace. Dym et al.(2005) support Castellion and Markham's finding stating that unsuccessful design results are common both in the classroom and in practice. Combining these findings with the opportunities presented in the last section, we believe that a systems-based, undergraduate design canvas can improve both student learning and successful product design.

Another objective of the work is to develop a "meta-canvas" approach that is comprehensive and rigorous, yet customizable, such that faculty can develop a canvas to suit their specific course(s). Customizability for different faculty approaches is vital, but an underlying metamodel used also helps make it clear where the boundaries to customizability lie. Existing canvases, with their inherent complexity, may be better suited to more advanced courses, and a customizable canvas approach may broaden the impact of the canvas concept from first-year design through capstone design and beyond. Faculty may utilize different approaches or have different learning objectives between introductory and advanced design courses. Customizability, with a consistent underlying metamodel, has been shown to enhance faculty members' ability to compare their activities and for students to see the commonality across their product designs.

Another objective in this phase of our work is to develop an information collection and synthesis tool that sets the stage for a more comprehensive model-based canvas in a second phase. A robust model-based approach shifts the emphasis from following the "right" process to synthesizing complete and aligned information and model representations (Schindel, 2015).

A final objective of the work is to propose a design teaching approach that creates and protects value, and importantly, maintains a clear focus on designing/developing complex technical systems in complex business environments. With the high product failure rates previously noted, many designs are simply not creating significant value for customers or stakeholders. The proposed approach should incorporate features as elements of stakeholder value and also support diverse measures of value including technical, financial, social, and environmental. As noted by Rust (Rust et al., 2006) and Blank (Blank, 2013), the right feature mix is an important factor in product success and creating value.

Developing the New Design Canvases

The design canvases developed in this paper are based on recent developments in the field of systems engineering. Schindel has developed an S*Metamodel which is "the smallest model sufficient to the purposes of engineering and science" (Schindel, 2011). As a metamodel and a generic representation of a system, it has been successfully applied in the design modeling of a wide range of industries, products, devices, and process systems (Schindel, Peterson, Shuebrook, VanZandt, Welling, 2016). For this design canvas work, the metamodel provides a robust foundation suggesting the minimum set of data and information necessary to describe the key representations of a system including interaction behaviors, design, and value provided.

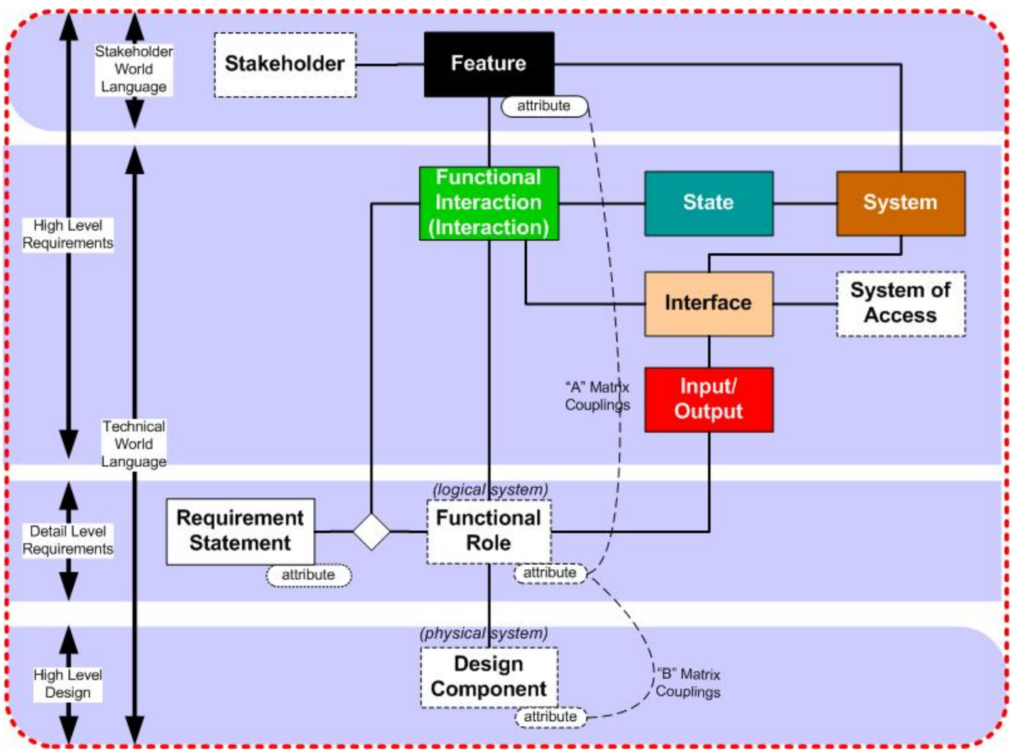

Figure 1 – The S* Metamodel (Schindel, 2011)

A key aspect of the S*Metamodel (Figure 1) is the focus on features. Features are the desirable properties that the stakeholders want the system to have. They are commonly the 'ables' and 'ilities' such as affordable, durable, usable, or repairable. Features are also expressions of stakeholder value and form the basis for the selection of one option over another. For example, a buyer selects a sports car because it has the desired features compared to a family van. The literature contains a variety of terms to express stakeholder desires including features, wants, needs, and constraints (Ulrich and Eppinger, 2011). We consider features to be a general expression of stakeholder value (desired or not) that encompasses the other terms. A 'need' is a feature with very high value or 'must have' priority, and a 'want' is a valued feature but with a lower priority (e.g., a feature that the user is more willing to give up when making tradeoffs).

It should also be noted that while features are a key element in product design, the value provided by them is not intrinsic to the product, but instead the value is intrinsic to a product's stakeholders. The "right" feature mix implies identification of the related set of stakeholders. This means that identifying the "right" set of stakeholders is just as big a part of achieving success as developing the right feature set. As a result, some innovators and entrepreneurial educators (e.g., Steve Blank) begin by identifying the segment of stakeholders, from which the "right" features follow.

Identifying the main model elements in Figure 1, we've developed a canvas to represent the S*Metamodel (Figure 2). This is a simple 1:1 mapping of main elements from Figure 1 to Figure 2, changing the visual representation from a diagram to a canvas with 9 boxes. The canvas includes simple titles in each block and simple prompts that suggest what type of data and information should be collected/synthesized in the block. (Note: Table A in the appendix provides a description of each canvas element along with examples of the type of information that might be collected in each box.)

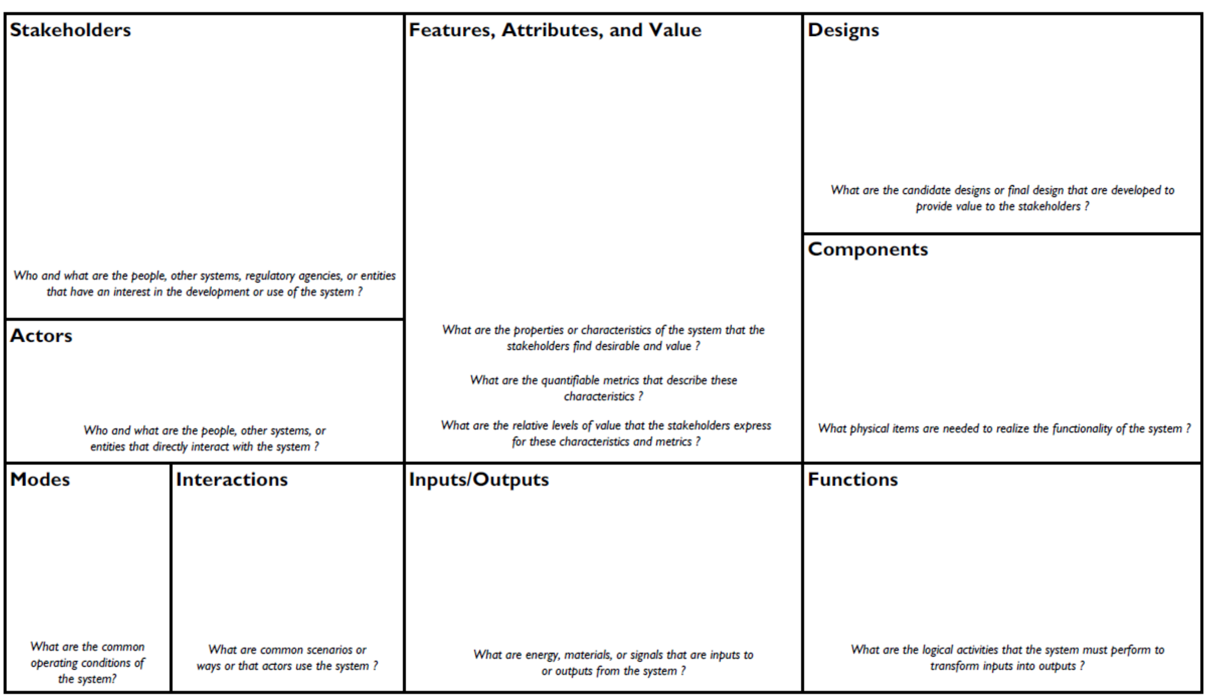

Figure 2 - Design Canvas 9

Synthesizing Figure 2, in Figure 3 we highlight three larger sectors which representing the fundamental divisions of the S*Metamodel; those being, Value, Behavior, and Design which will carry over into a more comprehensive “model views” canvas to be presented in a subsequent paper. At this level, the canvas can be used for information collection and conceptual evaluation of design concepts. Instructors could use the canvas as shown or they could develop block titles and prompts more tailored to their courses and designs studied.

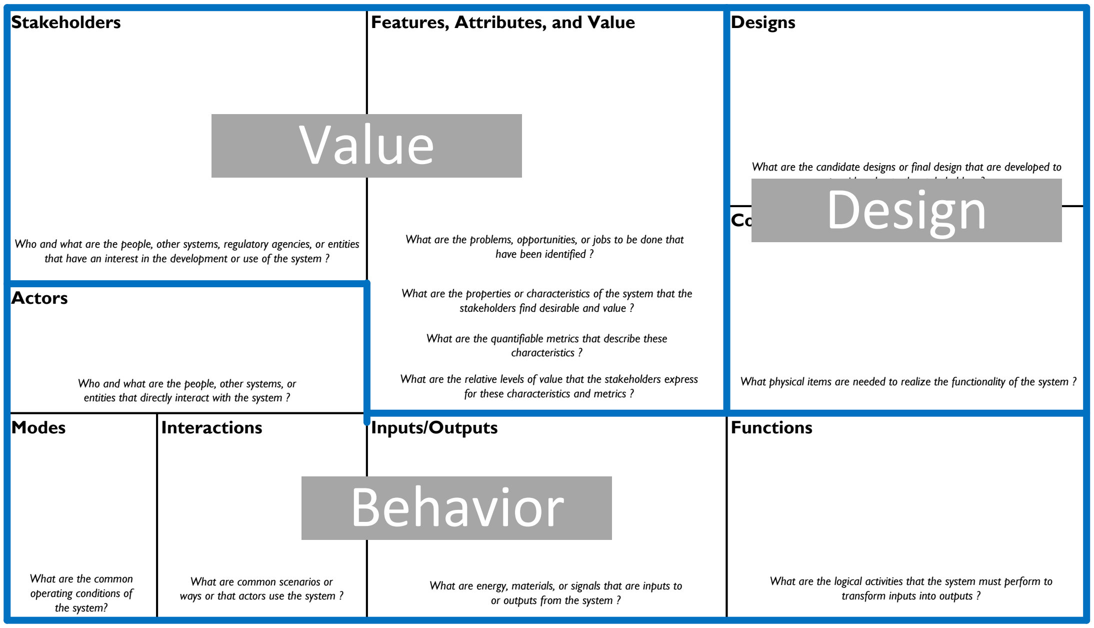

Figure 3 – Design Canvas 9 with Highlights of the Three S*Metamodel Divisions of Behavior, Design, and Value

At the conceptual level, students or users can work with the canvas as a dashboard to collect key information and develop trial design concepts. Exploring trial designs at the conceptual level can be done very quickly to confirm overall completeness and alignment of the concept without a significant time/cost invested in detailed design or prototyping work. The canvas approach naturally encourages the iteration in design that should occur but is sometimes missed in a linear approach.

Connections Among Canvas Elements and Design Elements

The primary dependency connections between canvas elements are shown in Figure 4; however, in reality all elements are indirectly connected. The significance of these direct, and some indirect, connections are detailed in Table 2. These connections are often key teaching points or represent critical factors leading to successful designs. Table 2 also identifies many design tools that are commonly used in the related step of the design effort. These design elements include the needs/metrics matrix, house of quality, sequence diagrams, or Pugh matrix. With the canvas serving as a higher-level dashboard, when students explore the design of a system with the canvas, they are collecting, organizing, and aligning the information needed to construct the more complicated models and effectively utilize the design elements.

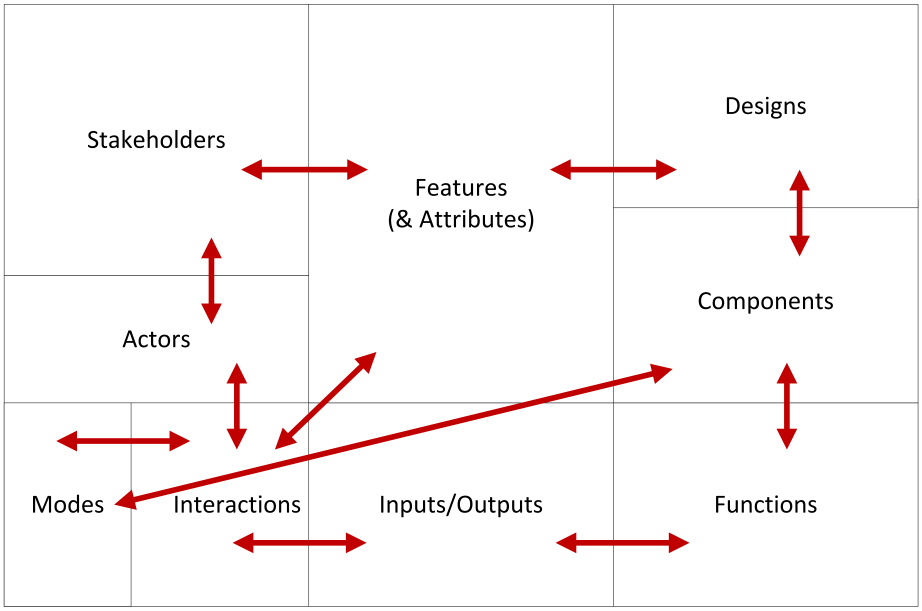

Figure 4 – Alignment Dependencies Among Canvas Elements

Element 1	**Element 2**	**Significance**	**Model Element**
Stakeholder	Features	Features (w/ Attributes) define value provided by the system.	Stakeholder/Feature Table, Needs/Metrics Matrix, House of Quality
Stakeholder	Actor	The groups of Actors and Stakeholders often have common members.	
Actors	Interactions	All Actors are included in interactions	Sequence Diagrams, Use Case Diagrams
Modes	Interactions	Interactions happen in modes	Mode/State Diagram
Interactions	Inputs/Outputs	All I/Os are included in interactions	Domain Diagram, Requirements
Interactions	Features		
Inputs/Outputs	Functions	Functions process all I/Os	Functional Architecture
Functions	Components	Functions allocated to Components with Modularity decisions	Generic Physical Architecture
Components	Designs	Evaluate candidate designs relative to benchmark using features and attributes.	Multiple Candidate Designs, Morphological Matrix, Weighed Decision/Pugh Matrix
Features	Designs	Evaluate candidate designs relative to features	Feature/Design Table
Modes	Components		

Table 2 – Connections Among Canvas Boxes and Design Elements for Each Box

A simplified design canvas is shown in Figure 5 with six boxes. This Design Canvas 6 version would support examining stakeholder wants/needs (#1), actors that interact directly with the system (#1), review of functionality of existing alternatives (#1, 2), propose a new design (#2, 3), and project reporting (#4, 7). Even with fewer boxes, students are still exploring the key elements of the full underlying systems model.

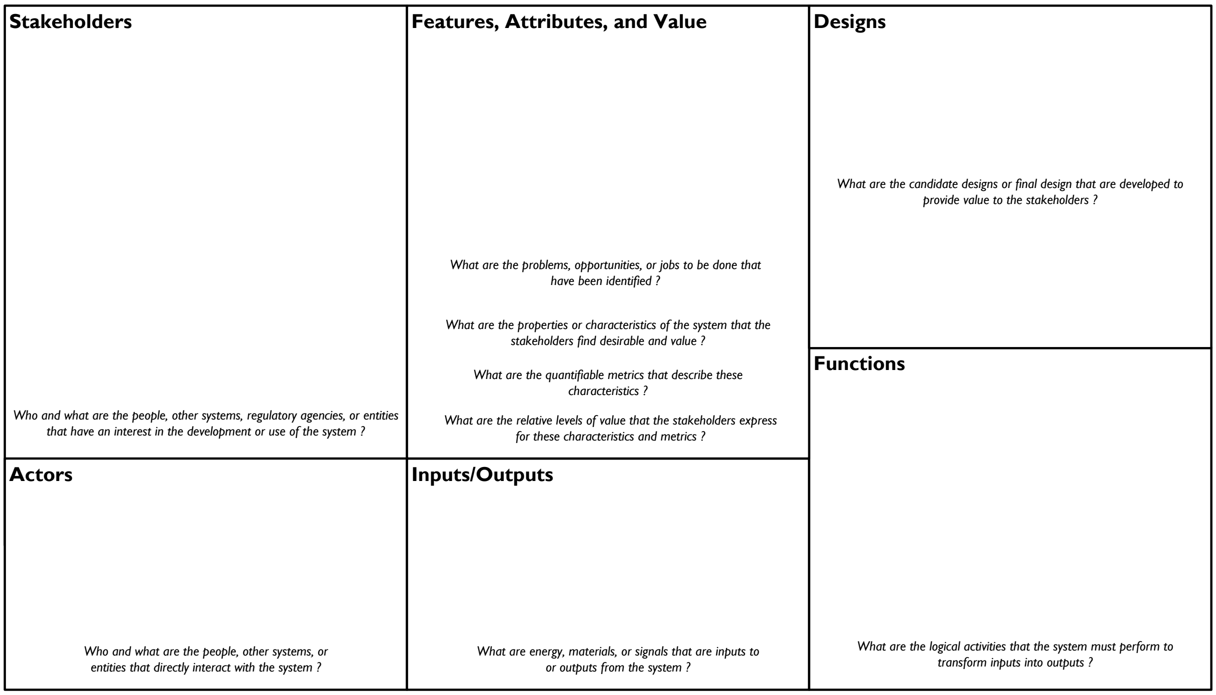

Figure 5 - Design Canvas 6 - Simplified Version

Emphasis on Creating Value

The canvas approach described in the previous sections provides a clear focus on creating value in the design process as it is founded on a metamodel that emphasizes product stakeholders and features. The approach encourages the identification of a range of relevant stakeholders along with the key features important to each. This explicit and comprehensive view of both provides the ability to assess completeness and alignment of both. As noted previously, a designed system may fail to find success as a result of overlooking important stakeholders or including too many or not enough features. The key consideration here is that the value created lies at the intersection of stakeholders and features. Thus, value, embodied in product features, is not inherent in the system by itself, but is judged by the stakeholders based on the attainment of features provided by the final design in the context of external interaction with the environment.

Including Design Considerations Beyond Technical and Financial

An objective of new ventures is to achieve commercial success through developing the right product offering. The Business Model Canvas approach highlights this objective with a clear emphasis on costs, revenue, channels, and market segments. In addition to technical and financial factors, ABET requires that students consider complementary priorities in design such as environmental, social, political, ethical, health and safety, manufacturability, and sustainability. The proposed S*Metamodel canvas approach accommodates these considerations in a straightforward manner by including them directly in the iterative design process as essential information needed to identify and understand stakeholders as well as develop relevant features. Sustainability could be included in the design canvas by identifying the environment as the stakeholder with 'sustainability' as the general feature. Two possible attributes could then be carbon impact and recyclable materials. Both of these attributes are more quantifiable and measurable characteristics. Other objectives could be accommodated in a similar manner through features and feature attributes.

Example of Design Canvas Applied to IDEO Shopping Cart

The IDEO shopping cart has become a classic case used in design courses as a first day or week exercise to view a sample process design and assess the pros/cons of it. The utility of the design canvas approach is illustrated with this case.

Step 1 – Students view the video and collect information during viewing. This information is collected on Post-it notes and attached to the canvas (Figure 6). As information is not presented in an orderly manner during the video, students must gather and categorize the relevant information during viewing.

Step 2 – Begin a guided discussion exercise addressing a variety of questions assessing the completeness and alignment of information. A series of questions could explore a variety of issues:

- What did IDEO consider and what did they miss?
- Did they include a good set of features, what should they have included?
- Did they include all the relevant stakeholders?
- Would their cart be successful in a Whole Foods versus a Walmart?
- What features or attributes would make it more suitable for a Walmart environment?
- Did they get a complete view of affordability and where might they have gone for a more realistic view of it?

Step 3 – Review the iterative process followed to collect information and develop prototypes. Students could analyze how the IDEO designers moved through the collection and refinement of information during the project.

Step 4 – Develop detailed models and design elements. Using the information collected, students could develop a variety of models including interaction diagrams, a domain diagram, a needs/metrics table, and functional or physical architectures.

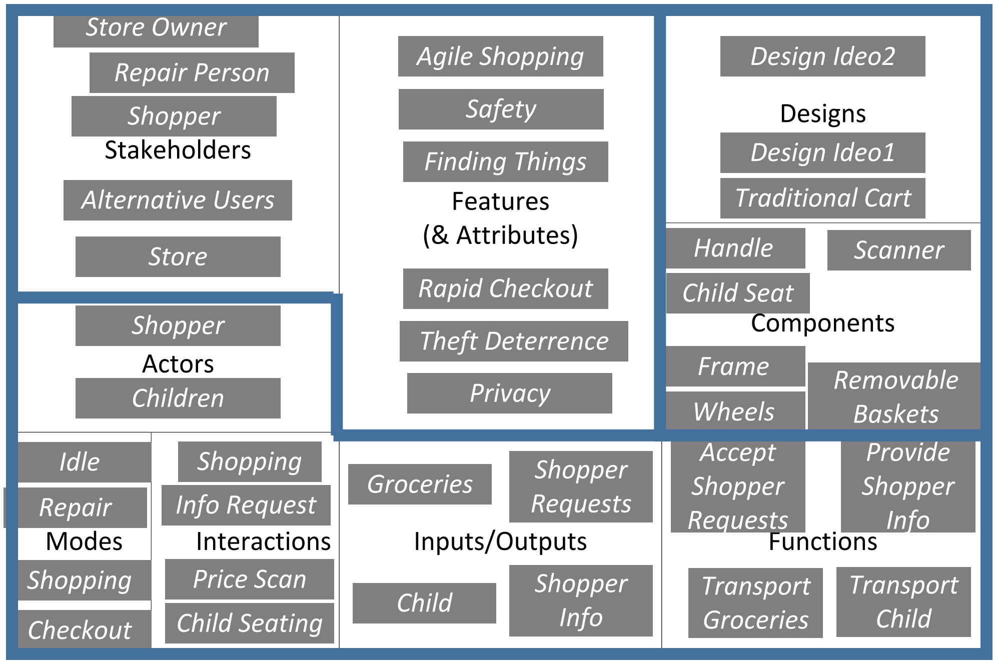

Figure 6 - Sample Design Canvas 9 for IDEO Shopping Cart

<u>Assessment Results</u>

The design canvas with 9 boxes has been tested in an upper level design class and student reactions/feedback were assessed. Students were given a paper handout of the design canvas with the question prompts, asked to view the IDEO shopping cart video, fill in the canvas with information during and after the video, and respond to an online survey and questions at the end. Table 3 shows students' responses to the question, "To what extent to you agree with the following statements about the canvas: The canvas helped me …" Students found the canvas to be helpful in identifying, categorizing, and finding gaps in the information. They found the canvas somewhat helpful at distinguishing between process followed and information collected and much less helpful at assessing the success of the design.

The canvas helped me ….	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Top Two (%)
Identify information in the case	0	0	0	15	5	100
Categorize information from the case	0	0	0	13	7	100
Identify gaps in the information collected	0	0	2	15	3	90
Assess if the IDEO design was successful or not	0	4	10	3	3	30
Distinguish between the steps IDEO followed and the information that IDEO collected	0	1	5	11	3	70

Table 3 – Student responses to Agree/Disagree Questions (n=20)

Students were also asked to identify the three canvas elements that were the easiest time to complete as well as the three elements that were hardest to complete. Table 4 is sorted by the "easiest" column and the "hardest" column follows a nearly inverse pattern. According to students’ responses, stakeholders and features were the easiest elements to complete and modes and functions were the most difficult. It is noted that the simplified design canvas with six boxes includes the top four easiest elements, suggesting that it may be more suitable for less experienced designers and first-year engineering student. However, further assessment is needed.

	Easiest (%)	Hardest (%)
Stakeholders	85	5
Features, Attributes	80	10
Actors	55	25
Inputs/Outputs	35	30
Components	15	25
Designs	10	40
Interactions	10	45
Modes	10	55
Functions	0	65

Table 4 – Student Results for Easiest/Hardest Items to Identify (Percentages, n=20)

Extensions and Future Work

The adoption of a systems engineering and model-based approach leads to a shift in thinking about teaching design and entrepreneurship. The work of Osterwalder in developing the Business Model Canvas and the reliance on a system meta-model in this work shifts the teaching emphasis from a process-based (step-by-step) approach to a model-based (information collection and representation) approach. Interestingly, Schindel (2015) notes this distinction as the difference between “maps versus itineraries”. He notes that early explorers and mariners could navigate successfully by following itineraries (process steps) in the absence of accurate maps of the world. Similarly, armed with Maxwell’s equations, we are less likely to see a circuits class teaching a “process” for designing a circuit—instead, the equations provide set of model relationships that have to be satisfied, no matter what process is used to satisfy them. Further work will continue to explore this process-based versus model-based view and will delve deeper into the underlying model views organized into three themes of behavior, design, and value as shown in Figure 3.

Summary and Conclusions

This paper adopts a model-based design approach from the field of systems engineering and applies it to the development of a canvas useful for collecting and organizing early stage data in a design project. As the proposed canvas is based on an underlying meta-model, instructors can scale and adapt a canvas for their course and learning objectives. Two canvases were proposed with one being suitable for a first-year design course (Design Canvas 6) and a more comprehensive one suitable for upper level or capstone design courses (Design Canvas 9). We believe this approach will encourage more faculty to explore using a canvas approach in their classes with the expected benefits of encouraging students to 1) collect enough of the right information before they start designing and 2) adopt a design completion standard of comprehensiveness and alignment of information (as opposed to simply checking off process steps).

Canvas Element	Description	Examples
Stakeholders	A Stakeholder is any individual, other system, or even an organization with a legitimate interest in the development, use, or outcome of the system. (from Systems Engineering Simplified)	User, Buyer, Maintainer, Other Systems, Regulatory Agencies, Environment
Actors	An Actor is any individual or other system that interacts directly with our system. The groups of Actors and Stakeholders often have common members.	User, Maintainer, Other Systems
Features	Features are the desirable properties of the system that the Stakeholders want it to have. Features are often the 'ables' and 'ilities'. Features are measures of value provided by the system to stakeholders. Features are the basis for Stakeholders choosing one system over another. A Feature may be described in general terms.	Easy to Use, Affordable, Reliable, Accurate, Repairable
Feature Attributes	Feature Attributes are the quantifiable metrics used to define the attainment of features. There may be more than one attribute for each Feature.	Cost, Price, MTBF, MTTR
Interactions	Interactions define the exchange of Inputs and Outputs between the system and Actors. An interaction describes a scenario or a use case.	
Modes	Modes are the different conditions of behavior of the system that are likely to be recognized by the Actors	Off, Idle, Operating, Warm-Up, Maintenance
Inputs/ Outputs	Inputs and Outputs are the energy, materials, or signals exchanged between the system and Actors during interactions.	Electricity, Fuel, Water, Parts, Request Information, Acknowledge Request
Functions	Functions transform inputs into outputs. A group of functions can be used to describe the behavior of the system. Functions are described with 'verb+noun' names and describe what the system does, not how it does it.	Accept Inputs, Provide Outputs, Process Control Signals
Components	Components are the physical subsystems or items with requirements allocated to them that make up the system. Functions are allocated to Components.	Power Supply, CPU Board, User Interface, Keyboard
Designs	A Design is a collection of components with allocated requirements. There may be multiple system representations possible through functions and components. A final Design is selected by evaluating candidates relative to requirements and features.	Design 1- Basic Design 2 – Modular Design 3 – High Performance

Table A – Description of Canvas Elements with Examples

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