Engineering Design, A Shift From a Process to a Model-based View

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***Abstract*— A design education approach is presented using a model-based framework emphasizing information collection and construction of model views. This approach is based upon a "meta-model" from the field of systems engineering and includes a keen focus on creating value as a primary outcome. With a model-based approach, the emphasis shifts to information collection and synthesis and away from the traditional representation of design as a following a sequence of tasks and steps. Two recent developments applying this model-based approach are presented and illustrated with examples. Early classroom results indicate that these new approaches may help to improve student outcomes.**

***Keywords*— design, design process, design models, canvas, creating value, systems engineering**

I. Introduction

The representation of the design process as a series of steps or activities has been a standard in engineering design courses for many years. In spite of this widely held view, both student and more informed designers struggle to achieve consistently successful results with this approach. To address several of the shortcomings of inexperienced designers, an approach to design education is presented using a model-based framework emphasizing information collection and construction of model views. This approach is based upon a systems "meta-model" from the field of systems engineering and includes a keen focus on creating value as a primary outcome. Two recent developments applying this model-based approach are presented and illustrated with examples. This new approach has been applied in several design courses, and "canvas" frameworks have appeared that create a visual tool for analyzing the design problem at hand.

II. Design is Difficult

In a classic work reviewing the design teaching and learning landscape, it is noted that "design is hard to learn and harder still to teach" [1]. In addition, the distinction is made among the design process followed, the information collected, and the final design outcome. Supporting this assertion of the challenges in teaching/learning design, unsuccessful design results in the classroom and in practice are common. Despite the availability of software based design tools and access to consumer preference data, some 40 percent of new products developed by expert designers still fail to find success in the marketplace [2].

A study of designers has compared the traits of student designers compared to more successful and informed designers [3]. Nine design strategies are identified and the traits displayed by beginning and more informed designers are compared relative to these strategies. Several shortcomings of inexperienced (student) designers are noted including they 1. don't collect enough or the right information before they start designing, 2. focus on just one or a few ideas, 3. fail to consider a range of options, and 4. follow a simple linear path or other unsuccessful process when conducting the design.

III. Design as a Process

Engineering educators have represented the design process as a series of steps for some 50 years [4,5]. This process representation documents the main components of successful design, but it is noted that students may fail to grasp the significance of the steps. It is also noted that this design process view makes more sense in a retrospective view of a successful design, but it breaks down when a novice attempts to apply the process to a real, more complex design project. Finally, it is suggested that educators must develop a design education approach that encourages synthesis as well as analysis [4].

A collection of over 120 "design models" has been presented and all representations cited view design as a process and describe sequences of design activities, steps, or iteration [6]. The representations do not clearly describe the information that needs to be collected or synthesized to complete a design. An example of a representation of design as a process is shown in Fig. 1 [7].

IV. Design as an Information and Model-based Actvity

Building on findings presented in previous sections that design is represented as a process, unsuccessful design outcomes are common, and inexperienced designers often don't collect enough or the right information before starting a

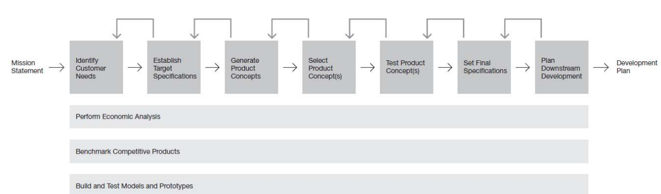

Fig. 1 – The Design Process from Ulrich and Eppinger [7]

design effort, an information or model-based view of design is proposed. The design of a system is represented as an integrated set of information with the process to collect the information less important than the completeness and alignment of the information collected and models developed.

To represent design as an information collection activity, insights into the appropriate level of information to be collected are found in the field of systems engineering. The Systematica meta-model shown in Fig. 2 represents the minimum set of information necessary to describe the behavior, structure, value, and design components of a system [8]. Adopting this perspective, the design effort is then represented to students through an information and model view as shown in Fig. 2 (or Fig. 3) rather than (or along with) the design process view.

We use the term "model" as the underlying relational information that is commonly viewed as qualitative and quantitative models such as text, tables, block diagrams, or graphic representations. As the field of systems engineering has evolved to a model-based approach, a variety of views have replaced the more conventional approach of describing systems with volumes of prose.

V. APPLICATION TO ENGINEERING EDUCATION

To more fully illustrate educational application, Table 1 show the items of information identified in Fig. 1 with corresponding model views possible for each item. Students would collect this information and develop the model views in the second column as part of a design project [9]. Some of these items and views are known such as requirements and functional models and may currently be collected in design projects but often not in a comprehensive and integrated manner.

The model-based approach has been documented and tested in undergraduate design courses and particularly capstone design [9]. Benefits of the approach include the ability to design/model a wide variety of systems with a common collection of views which makes the approach easier for faculty to teach and assess. In addition, as new information is collected, iteration and refinement of model views are naturally encouraged.

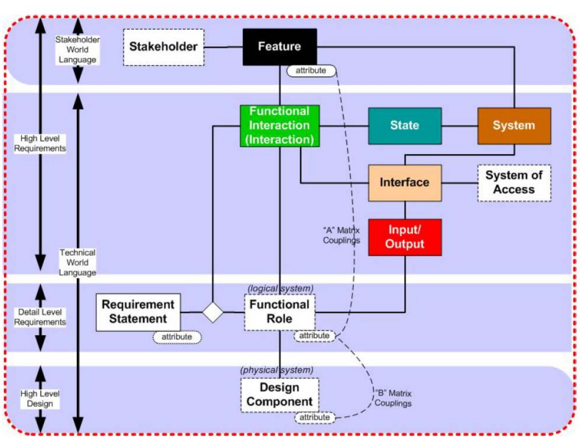

Fig. 2 – The S* Systematica Meta-model [8]

TABLE 1 – Information Items from Fig.2

Information Items from Fig. 1	Possible Model View
Stakeholders	Stakeholder Feature Table
Features	Stakeholder Feature Table
Interactions	Sequence Diagram, State Diagram, Domain Diagram
States/Modes	State Transition Diagram
Inputs/Outputs	Input/output list, Domain Diagram
Interfaces	Interface table, Domain Diagram
Functions	Domain diagram, Functional architecture diagram
Requirements	Text
Design Components	Physical architecture diagram

The model-based approach has also inspired the development of several canvas representations of systems and design. The Business Model Canvas is a simplified representation of a more complex prose-based business plan [10]. The Innovation Canvas and Design Canvases are more direct applications of this model-based approach to encourage students to collect and synthesize information during a design project in a business context [11,13]. Both canvases are made available under Creative Commons licenses. A Design Canvas with nine boxes is shown in Fig. 3 below. The canvas can be used by educators and students during a design project to collect, synthesize, and align information during the work. This view of design presented to students suggests what information they need to collect rather than what process they need to follow.

Preliminary assessment results have been collected for the design canvas [13]. Students in an upper level design course were asked to view the IDEO shopping cart video, populate the canvas with information while viewing the video, and respond to an online survey. Table 2 shows results indicating they 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.

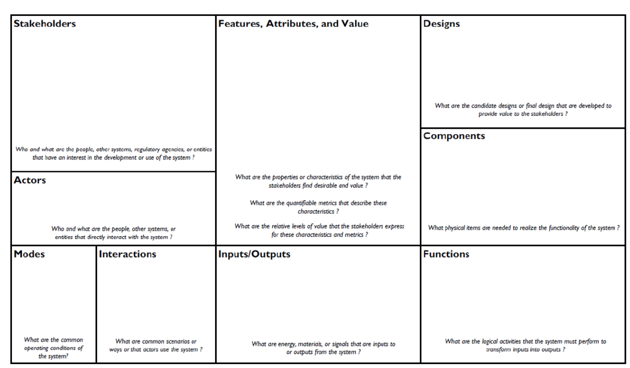

Fig. 3 – Design Canvas with Nine Boxes [13]

TABLE 2 – Assessment Results Using Design Canvas [13]

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

VI. Conclusions

An approach to design education has been presented using a model-based framework emphasizing information collection and construction of model views. The design of a system is represented as a complete, integrated, and aligned set of information with associated model views. This proposed representation is then complementary to the established view of design as a process. Insights from the field of systems engineering provide guidance on the minimum set of information necessary to describe the behavior, structure, value, and design components of a system design. Recent developments have applied this new approach in undergraduate design courses and in the development of canvas tools that create visual dashboards for information collection and synthesis. Preliminary assessment results indicate that the new approach may help to improve student outcomes in design projects but more study is needed.

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