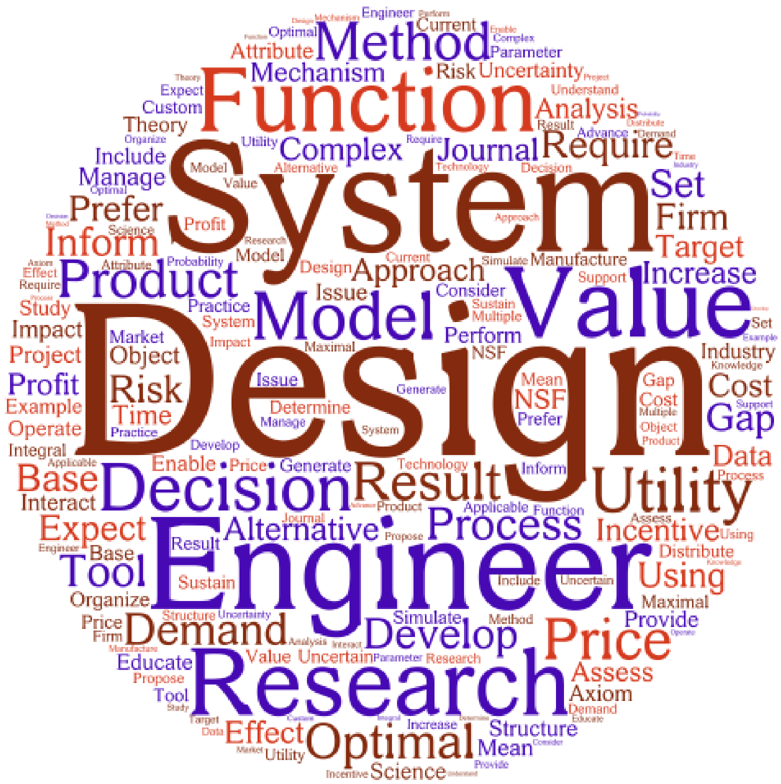
THE CIRCLE OF DESIGN



An NSF sponsored workshop on Education, Validation and Dissemination, and Research Directions in Engineering Design and Systems Engineering held at Clemson University, Clemson, South Carolina.

Final Report

June 2016

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PREFACE

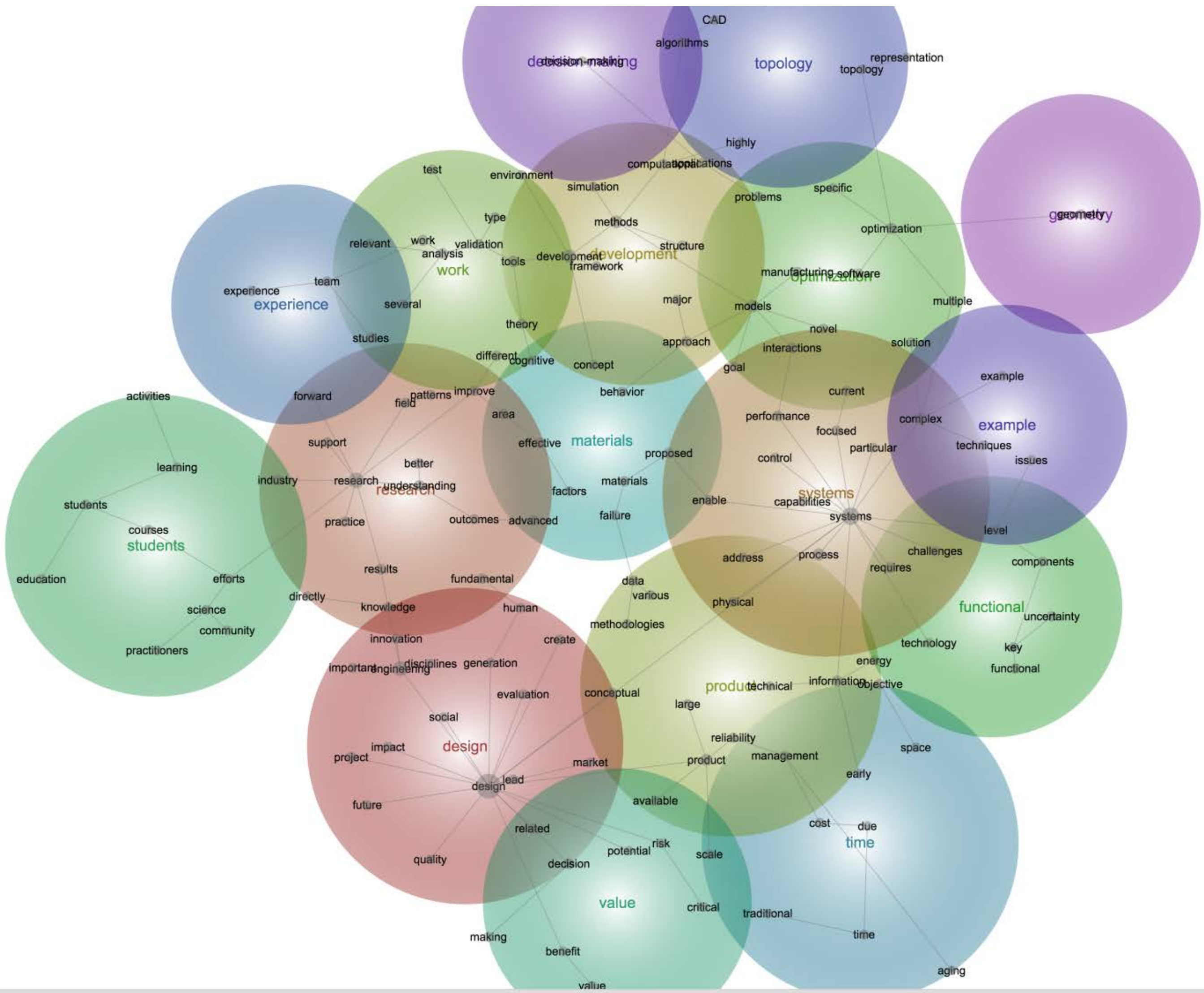
This report is based upon the findings of a workshop supported by the National Science Foundation under grant # 1550242. The workshop was held at the Madren Conference Center of Clemson University in Clemson, South Carolina from November 14-17, 2015 and was hosted by Clemson University. The aim of the workshop was to bring together two communities, namely the Engineering Design and the Systems Engineering communities and have them in common address three topics:

- Directions and needs for systems engineering and design theory and tools. Formulating strategic recommendations for systems engineering and design research in general, and ESD, SYS in particular
- Systems engineering and design research methodologies, developing guidelines for rigor, evidence based best practices, validation, and dissemination of approaches, commonalities, and differences in other domains
- Systems engineering and design education, its focus, desired impact, evidence of success, including organizing industry workshops in various locations to train industry practitioners on modern systems engineering and design methods and tools.

Additionally, an NSF grantees poster presentation session was organized. The posters presented along with short two minute elevator pitches as well as the present report are available on the Circle of Design website at: http://www.clemson.edu/centers-institutes/design/workshop/index.html).

The contents of this report summarizes the discussions and conclusions of the participants. It is derived partially from short position papers written by the participants, discussions between the participants, and summaries prepared by the facilitators. The participants who did not present a poster as a grantee (and others if they wished) were asked to prepare a one page document discussing their view of the state of the art in the Design and Systems areas. They were asked to highlight what they believe are the most relevant theories, methods and tools, how should these be validated, what is their own contribution, and what they believe is missing to move the fields forward. They were also asked to reflect on the education of practitioners, and what needs to be done to better prepare them. The Logo of the workshop on the first page and the figure on the next page provided by Prof. Subrahmanian show images of how the community sees itself when the information is mined from the essays submitted.

This material is based upon work supported by the National Science Foundation under Grant No.1550242. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.



Linguistic analysis map based on the pre-work essays

CONTENTS

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MEETING FORMAT

12 tables of up to 10 persons per table were set up to facilitate the discussions. At each table, a facilitator engaged the participants, took notes, and later summarized the participants' discussions. A student also attempted to capture notes and provided logistic support to the facilitator. Since the objective was to focus on three topics, four tables addressed a topic, and then the participants were asked to address another topic with other colleagues. Six rotations were planned and each participant was to address a topic twice with different colleagues. This did not happen ultimately as the discussions had to be refocused after several rotations. However, everyone felt they did provide input in all three topics.

Questions extracted from the participants' essays were presented to spur ideas. These were:

Systems

- Do we need a new methodology for studying and designing complex systems?
- How should we prepare engineers to deal with the complexities of dealing with systems that have emergent behaviors (more than the sum of the parts)?
- How are engineering systems properly decomposed?
- What do students need to know about uncertainty of complex systems?

Validation

- Will the availability of real world complex system design problems prevent researchers from properly validating their research methods?
- How well integrated on a global scale are research findings in the science of design? To what degree will improving this integration promote advances in methods and solutions?
- How well are scientific findings in design research verified/validated and what methods or requirements can improve this verification/validation?

Education

- How do you plan to implement the findings from research to improve education of future students?
- What are the challenges in teaching engineering students how to properly decompose engineering Systems?
- How do you teach students about the evolution of current design methods? What is the value in this?
- What are the essential elements of design and systems that need to be inculcated in design and systems education? At what do these new methods affect the design process?
- How we educate and provide exposure to engineering students which will allow them to design for an international market?
- How is effective content delivery ensured?
- How can we train the next generation engineers/researchers account for the increase in complexity of the system in trying to accommodate the future designs?
- What teaching methods can better prepare future practitioners on how to address systems design?

Future Design Research

- Are there differences in how to foster creativity across disciplines of engineering and other design disciplines?
- What new research techniques should be considered in design research?
- Design methods are often applicable within a range of parameters, but not in an infinite domain of scenarios. How do we properly bound design methods and tools?

- How can the gap between design research and design practice be minimized? What are the challenges in doing so?
- What factors contribute to the lack of industry implementation of researched design methods?
- What are the primary advantages of the open and cooperative model of product development? Are there any limitations or drawbacks?

SCHEDULE

Day 0 Saturday 11/14		**Participants arrive at Greenville Spartanburg (GSP) airport and are picked up by shuttle or fly to Atlanta and drive to Clemson (45 minutes or 2.5 hrs respectively)**
12:00pm-7:00 pm		Shuttle van from GSP to Hotels every hour (2 vans)
2:00pm – 6:00pm	Social 0	Golf for those interested at the Madren Center or walk in the botanical gardens
2:00pm - 5:00pm	Org 1 – EIB 132	Meeting with workshop facilitators and graduate students to organize workshop in the ME department at Clemson
7:00pm-9:30pm	Session 0 Ballroom	Working dinner and inaugural session. Address by NSF program director and Hosts - Program review and workshop charge
Day 1 Sunday 11/15		
9:00am – 12:00pm	Social 1	Walk and talk on Clemson Campus and Botanical Garden
12:00pm -1:30pm	Lunch	Lunch boxes provided – Ballroom
1:30pm-3:00pm	Keynotes	Jami Shah and colleagues – Standing on the shoulders of others: sharing research products and data
3:00pm – 3:30 pm	Coffee	Posters in Ballroom
3:30pm-5:00pm	Session 1	Discussions on topics in groups of 10
7:00pm-9:00pm	Social 2	Dinner and social
Day 2 Monday 11/16		
8:30am -10:00pm	Session 2	Discussions in groups of 10
10:00am –10:30am	Coffee	Posters in Ballroom
10:30am –12:00pm	Session 3	Discussions in groups of 10
12:00pm – 1:30pm	Lunch	Social
1:30pm – 3:00pm	Session 4	Discussions in groups of 10
3:00pm – 3:30 pm	Coffee	Posters in Ballroom
3:30pm – 5:00pm	Session 5	DiscusGrantees conference – Poster session in Ballroom
5:00pm – 6:30pm	Social 3	Walk and talk
7:00pm – 9:00pm	Social 4	Dinner and social
Day 3 Tuesday 11/17		
8:30am -10:00pm	Session 6	Discussions in groups of 10
10:00am -10:30am	Coffee	Posters in Ballroom
10:30am–12:00pm	Wrap up	Presentations of some key points from all three topics
12:00pm-1:30pm	Org 2	Lunch Madren Center restaurant for facilitators
12:00pm – 6:00pm		Shuttle to GSP airport
1:30pm - 5:00pm	Org 3	Initial drafts of report

SUMMARY RECOMMENDATIONS

A. FUTURE RESEARCH DIRECTIONS

A.0 Introduction

Participants in the "future research directions" sessions were first invited to offer important, unanswered questions in engineering design and systems engineering in a freeform manner. During the remainder of each session the participants engaged in a discussion to clarify and augment the list. Upon completion of the sessions, the facilitators organized the questions into several categories. The categories are discussed below, and the questions for each are listed. These are not organized according to their relative importance, but rather according to the domains they represent.

A.1 The Design Process, Representations, and Modeling

Essential to conducting research on systems engineering and design is an understanding of the fundamental nature of the design process. As has been noted in the literature, the participants in these sessions agreed that design can be characterized as a search for solutions in a space of possible designs. Designers sample ideas from a distribution of possibilities from this design space. Thus, the engineering design process consists of first identifying and expanding the design space, then contracting the space while converging on a solution. This is a broad characterization of the process, and there is still need for descriptive research on the entire design process to answer such questions as:

- What are key decisions in the process?
- In which stages of the process do designers focus their work? How is the workload distributed throughout the process?
- If changes in the process are called for, what is the cost of that change?
- What aspects of the design process can be formalized? How do we manage the aspects that cannot be formalized?

The design research community has many design tools and techniques focused on the various stages of the process, such as understanding customer needs, concept generation, and engineering decision-making, among many others. However, the limitations of these tools and techniques are not always clear. We need clear criteria to match the proper tool to a given design problem. We need to be able to reproduce research results so that we can identify the applicability of a tool and have confidence that it will work. Fundamentally, we need to cross-classify design problems and design tools so practicing engineering designers can choose the best design tool. Since design is not deterministic, we need to be able to assess the risk of committing time and resources to the use of a particular design tool.

Much design research focuses on the design process itself, so that the long-term effects of design methods are unknown. There is a need to study the effects of a method all the way to the end stages of design, i.e., after the product or system has matured. How does the product sell? Does the system perform as predicted long term? There is a need to follow the product through its whole life to understand, for instance, reliability and cost to maintain the product or system throughout its life so that accurate risk assessment can be conducted.

Similarly, the participants noted that much research on the design process is conducted (perhaps by necessity) on simplified problems. There is often little evidence that the resulting methods will scale to large "mega-systems", such as energy systems, space stations, and large aircraft. The community should focus on developing ways to verify the scale of applicability of the results of their research.

There is growing demand today for systems consisting of integrated products and services. In some cases, the distinction between these two aspects of a system is blurring as to which is more important to the customer. Recent studies have focused on characterizing the unique issues of designing such systems, and initial attempts have been made to adapt design methods to this domain. However, opportunities to create new approaches to this simultaneous design challenge are emerging and merit attention by the community.

A.1.1 Related Questions

The participants identified numerous other research questions related to the characterizing and enhancing the design process, including the following:

- The engineering design process is often characterized as a transformation from function to form. How can we systematically map functional representations to geometry, materials, and other aspects of design?
- Engineering design is depicted as proceeding in stages that result in increasingly detailed information about the solution to the problem, from divergent thinking to convergent thinking. How can we effectively bridge the gap between the different phases of a design process?
- There is a 30 year history of research to automate aspects of engineering design, particularly the detailed, analysis-focused activities. Yet there is general agreement on the need for human oversight in design decisions. What is the proper role of automated approaches to engineering design?
- Increasingly design takes place on a global scale, across time zones and cultural boundaries. What tools and methods are needed to facilitate design across culturally diverse, non-collocated teams?
- Reproducibility of results is a key principle in the natural and social sciences, but is not practiced as widely in the design research community. Reproducibility is vital to

ensuring robust application of new methods. How do we demonstrate reproducibility of design methods and practices? How can we ensure methods are robustly practiced?

- Modern engineering practice is increasingly multidisciplinary. How do design researchers draw on other disciplines? When, which, and under what circumstances do engineers partner with other disciplines?

A.1.2 Action Items

Participants proposed the following action items for research on design methods and representations:

- Longer term (10 years) research grants to allow studies of the effects of design methods over the complete life cycle of products.
- Research initiatives involving colleagues from cognitive psychology to understand the mental processes required for successful engineering design.
- Support for studies of design in multiple engineering disciplines (electrical, chemical, mechanical, computer science, etc.) to understand how they relate.

A.2 Decentralized Design/Innovation

The growth of open systems and decentralized design teams calls for distributed innovation, both within the organization and also outside of the boundary of the organization (i.e., open innovation). Open systems and distributed design give rise to a range of opportunities and potential costs, which in turn lead to the question of the right level of openness, given considerations related to security, intellectual property protection, innovation, etc.

Furthermore, a research area is identified around the interplay of system architecture and organizational structure. What is the role of system/product architecture in driving distributed/open innovation? How do decentralized design/innovation processes affect the architecture of system/product? There is a need to formalize decentralized schemes for various stages of design, from ideation to validation.

These research areas are quite interdisciplinary and may benefit from a number of domains, including:

- Game theory: repeated games, cooperative games, Bayesian games, etc.
- Mechanism design and contract theory
- Complex/social network analysis
- Modularity theory
- Agent-based modeling/simulation

A.3 Understanding Humans in Design

One growing theme in engineering design research during the past decade is the need for exploring the intersections and interactions of people, products (including services), and systems. By understanding humans in design, we mean understanding both designers and users. Real design problems are not defined solely by technical concerns. They involve humans, groups, organizations, and societies, and they impact law and business, raising new issues related to ethical and environmental concerns that call for cross-disciplinary collaborations and research.

A.3.1 Common Challenges and Research Directions

The workshop participants recognize several common research directions underlying the study of either designers or users in engineering design. First, research is needed to better understand how people (designs and users) make decisions, namely how designers make design decisions and how customers make choice (purchase) decisions, respectively. Second, to support creative design (designers) and the elicitation of user needs and preferences (user-technology interaction), we need to address the question of how can designers best leverage technology with human activities. Third, to enable collaborative design, there is a need for studying the connection between social behavior and human performance (as a design team). The findings will also be useful for studying the social influence among members of a heterogeneous consumer group. Workshop participants identified a number of research challenges in understanding humans as designers and users. One common challenge is that the current research lacks sufficiently standardized measurements in empirical studies, which are commonly used for conducting cognitive and behavioral experiments. The other challenge is associated with the validation of computational models for behavior prediction, which is more complicated than validation of physics-based models.

A.3.2 Specific Challenges in Understanding Designers

Current studies in this area focus on creating cognitive models of design activities, e.g., sketches and text used for conceptual design, to enhance the designers' creativity in a design innovation process. Many existing techniques for building cognitive models are rooted in situated cognition, which posits that knowing is inseparable from doing by arguing that all knowledge is situated in activity bound to social, cultural and physical contexts. Because the design process inherently involves designers from many disciplines, a key design research area is communication and information sharing among diverse communities, together with a rigorous decision-making framework. Research opportunities lie in understanding the connection between the social behavior and the design team performance. With the computational social science approach, the challenge is to convert empirical processes into numerical results that show differences in different study groups. While methods like natural verbalization and commensurable measures have been used, sufficiently standardized measurements need to be developed.

A.3.3 Specific Challenges in Understanding Users

Whereas research in marketing explores actions that attract people to purchase products, research in design explores how we can change the design process to include consumer needs to produce more attractive designs (attractive means not only esthetics, but also functionality, performance, sustainability, and any other aspects that attract users) . Significant research into mathematical models and analytical modeling of consumer preferences should be integrated with the qualitative human-centered design principles to positively affect the design of products and systems. While analytical modeling of consumer preferences has been widely studied by the engineering design community in the past decade, challenges still exist for understanding and modeling changes in consumer preferences and how designers should respond to these changes. While traditional choice modeling techniques assume that consumers' choice behaviors are rational, in reality, irrationality occurs due to factors such as social influence. Alternative approaches are therefore needed to understand the complex relations between consumers and products, as well as social influences on such relations.

A.3.4 Suggested Methods and Bodies of Knowledge

Design research is distinguished from many other fields of research by the inherent need for knowledge and exploration that crosses the boundaries of multiple disciplines, including engineering, social science, arts and architecture, economics, business and management, computer and information science, and communication studies. The workshop discussion identified several key methods and bodies of knowledge that support understanding humans in design, including decision theory and economics theory, together with psychology, cognitive science, and computational social science. **Understanding humans in design calls for a deep understanding of the basic principles of design as a process of value creation, and from the education research point of view, a framework of learning**. Successful design research should disclose and address the challenging interdisciplinary issues in design, and provide a framework for integrating principles, methods (both qualitative and quantitative), and tools developed from multiple fields.

A.3.5 Other Recommendations

Future design research in understanding the role of humans (both users and designers) will not only build on the fundamental principles of design but will also exploit new and exciting research opportunities in crowdsourcing, social computing, web-based user analysis, human-centered design, network analysis, data mining, and many other fields. Recommendations were also made to collaborate with behavior and social sciences to study the human/social aspects of design through experiments, to integrate cognitive theory of modeling with computation, to establish empirical evidence-based investigations of design as a domain of scientific interests, and to apply the scientific method of inquiry to study design.

A.3.6 Related Questions from Position Papers

The following questions related to Understanding Humans in Design were gleaned from the position papers submitted by the Grantees:

- How should human factors be incorporated into complex system designs?
- How can we simulate human interaction with complex systems during all stages of the design process?
- How does design representation impact customer decisions?
- How do we balance human-centered and computational design of complex systems?
- Can crowdsourcing be integrated into the formal design process? If so, how? What research needs to be conducted to allow this?
- Most existing methods of capturing user-product interactions are intrusive. How does one move away from this, while respecting and protecting privacy?
- For certain quality related items like ergonomics and the user's feel of the product which are not easily quantified, what is the alternative?
- How to reconcile or complement the aspects of function, affordance, behavior?
- How do we model and validate models of customer preferences that are often inconsistent?

A.4 Uncertainty, Complexity, and Decision Making

Uncertainty, Complexity, and Decision Making are interrelated topic areas in engineering design. The past decade has seen a significant growth of research developments in these areas within the Engineering and Systems Design (ESD) community, as well as in a wide range of applications —from designing simple product components to designing complex engineering systems. While methods like "robust design" and "reliability-based design optimization (RBDO)" have become mature and widely adopted in computational design software, it has become evident that these techniques are mostly limited to handling parametric uncertainty. New methods and strategies for uncertainty characterization, problem formulation, preference elicitation, and risk mitigation are needed for managing many other sources of uncertainty, such as those associated with modeling and prediction, the design process itself, the product use environment, emergent system behavior, and the changing market.

A.4.1 Challenges and Research Directions

The workshop participants identified several key challenges associated with the research in uncertainty, complexity, and decision-making. First, under "Uncertainty", both theoretical and computational challenges need to be overcome. The theoretical challenge is associated with the quantification of various sources of uncertainty that are beyond parameter uncertainty, such as those associated with modeling and prediction, the design process itself, and changing markets. While various characterization approaches exist, some are ad-hoc in nature. It is therefore imperative to develop theoretically sound and self-consistent methods to quantify and manage various sources of uncertainties in a unified decision-making framework. In addition to the theoretical challenge, practical challenges of addressing uncertainty in engineering design include the consideration of "unknown" uncertainty due to lack of knowledge, e.g., uncertainty associated with the emergent behavior of a complex system. A related question is how can one trust the quality of data and the underlying model used to quantify the uncertainty (e.g., the use of Gaussian Random Process models to quantify the uncertainty due to lack of data)? Finally, while many efficient algorithms for design under uncertainty have been developed during the past decade, the computational challenge associated with high dimensionality and high nonlinearity still remains. This challenge is particularly critical for problems that involve uncertainty in both the spatial and temporal domains, such as in design of advanced materials systems.

Under "Complexity", the workshop participants considered the understanding of coupling and the emerging behavior of a complex system as one top challenge. Complex systems research calls for rational approaches for decoupling (decomposition). While simplifications cannot be avoided, the challenge remains to assess whether a simplification is "safe," and the relative benefits alternative simplifications may bring to a design process. Since design can be viewed as an information seeking process, the complexity of a design problem will be escalated to designing both the design artifact and the information seeking activities. This is a very complex decision-making problem due to its dynamic nature, i.e., decisions made in an early phase will have a direct impact on the subsequent phases. Methods are therefore needed to manage such complexity.

Under "Decision Making", participants considered problem formulation and preference elicitation under uncertainty as top challenges. While normative approaches promote collaborative design and the use of a single objective function, it is questionable whether design is truly collaborative in practice and how conflicts among different design groups should be properly addressed. Similar challenges exist for problems that involve multiple stakeholders, e.g., in design for sustainability.

A.4.2 Suggested Methods and Bodies of Knowledge

A few common streams of methods and bodies of knowledge were suggested by the workshop participants for this broad topic area. First, since design is viewed as a decision-making process, decision theory, economics theory, and Bayesian statistical inference methods should provide theoretical foundations to this topic area. Second, to study how people make decisions in design, researchers can draw upon the techniques rooted in psychology and cognitive science. Third, to address design conflicts associated with multiple disciplines and stakeholders, mechanism theory rooted in economics as well as organizational theory in management may provide the theoretical support needed. Finally, to respond to the “unknown” uncertainty, it was suggested that the principles underlying biological systems be studied to learn how nature responds to uncertainties. Analogous approaches might then be adapted in considering uncertainty in engineering design.

A.4.3 Behavioral Approach to Design Decisions

Research on design decision-making should continue, focusing on integrating designers into the design process. This includes an understanding of designers’ decision and choice models. Assuming a need for an axiomatic approach to modeling design decisions, what are the minimum sets of axioms we can agree on? How can we determine the value/utility function from the perspective of designer(s)? How do we aggregate the decision/choice models for multiple-designers/stakeholders?

Suggested methods for this research include:

- Decision theory
- Behavioral economics and choice modeling
- Social choice theory and preference aggregation

A.4.4 Other Recommendations

The participants agree that the research on Decision-Based Design conducted in the engineering design community during the past 20 years has provided a useful framework for addressing uncertainty, complexity, and decision-making issues in engineering design. However, beyond decision techniques, methods and tools are still needed for implementing the theoretical framework in real and practical engineering design problems, including in many other topic areas, such as concept generation and design evaluation. As decision making in engineering design is complex, heuristics and decomposition techniques cannot be avoided. New strategies need to be developed to help manage complexity. With regard to validation of the developed techniques, the participants suggested that, while a good decision cannot be simply evaluated based on the real outcome due to the many uncertainties involved, the general trend of decision outcomes can still be studied to assess “how good is the decision”, in addition to validation against the theoretical principles of decision-making. To manage the unquantifiable uncertainty, we need to develop new decision strategies such as those being examined in developing adaptive, reconfigurable, and resilient systems. Finally, the participants recognize that uncertainty quantification (UQ) is a truly interdisciplinary topic, and there is a much broader community beyond engineering design that studies the topic. Even though huge investments have been made by government agencies such as AFOSR, DARPA, DOE, etc. on Uncertainty Quantification (UQ) research, much of the funded research lacks rigorous theoretical foundations and does not address the strong connections between UQ and engineering decision making. It is recommended that the ESD program at NSF take a leadership role across multiple agencies and programs in providing the theoretical foundation for UQ research.

A.4.5 Related Questions from Position Papers

The following questions related to Uncertainty, Complexity, and Decision-Making were gleaned from the position papers submitted by the Grantees:

- How can uncertainty be quantified in subsystems designs and how should it propagate to the overall system model?
- How does uncertainty in design affect verification and validation of design tools?
- How should we teach uncertainty and uncertainty propagation in complex systems to students?
- Intelligent systems are powerful enablers that also carry inherent information security risks. How do we balance the potential benefits and risks in design?
- How and when can we best introduce stochastic concepts and uncertainty to engineering students?
- How is reliability of acquired data ensured? Can we get genuine data from error signals?
- Complex systems require interaction between people from many different professions and government agencies. How do we manage the complexity of government regulations and minimize risk without stifling innovation?
- How do we combine subsystems into a complete system while maintaining robustness?
- How do we design reliable systems? What does reliable mean? How does reliability change with time?
- How do we evaluate the robustness of a design during the conceptual design stage?
- How can we design systems that are robust to technology changes?
- How will the pursuit of elegance impact the robustness of a system?
- During the early stages of design, can all the design data be put into a medium-neutral and format-neutral representation?
- How can we measure the progress of a systems' engineering project using metrics besides time or money?
- What current methods can be used to integrate knowledge in multidisciplinary engineered systems?
- Are existing information representation techniques equipped to handle the concept of "gist"? How does one use "gist" while designing complex systems?
- Do the architectures of representation languages need to evolve with the evolving/increasing complexity of systems?
- Information systems must evolve to unobtrusively capture as much data as possible from a project. This is essential for retrospective case studies and validation. How must current information systems evolve to allow for this?
- Can we look at the previous iteration/version of a state-of-the art system and predict its evolution in the future?

- Can we predict system reliability and system obsolescence by gathering historical data pertaining to a product's evolution?
- How is "value" best measured in engineering design, both in monetary and non-monetary terms?
- How should we introduce the concept of value to undergraduate students?
- How should value realized in the latter stages of product life, such as maintenance, be incorporated into design decisions?
- How do we assign value to sustainability?
- How does the evolution of technology affect the usability (value and robustness) of complex systems in the future?
- Is there an economic consideration associated with decision-making?
- Can we justify uncertainty based decisions economically?
- Do we need a new methodology for studying and designing complex systems?
- How should we prepare engineers to deal with the complexities of systems that have emergent behaviors (more than the sum of the parts)?
- How should engineering systems be properly decomposed?
- How can mathematical models of complex systems help manage the complexities of multi-disciplinary design?
- How can we teach students the difficulty of making complex systems engineering design decisions?
- What design strategies are needed to ensure that complex systems are simple to maintain and operate?
- How can we simulate human interaction with complex systems during all stages of the design process?
- How does a functional basis help complex system design during the conceptual design stage?
- How can we identify failure modes of complex systems early in the design process?
- How can we identify undesirable emergent properties of complex systems?
- How can we integrate non-functional requirements (like safety) into complex system design?
- Can research results on problem decomposition strategies of dispensing facilities design (e.g., medical facilities) be applied to other complex systems design problems?
- How must simulation techniques evolve to capture the dynamic nature of complex systems?
- How do we update a system if a new uncertainty factor is encountered or found?
- How are the different types of complexities defined?
- How do aspects like elegance and affordability influence complexity of a system?
- How can metrics be developed to consistently measure different complex systems?
- How can we move towards a more efficient design platform in complex systems with emphasis on communication and collaboration?
- What are the drawbacks for requirements-based design that prevent it from addressing complex design problems?
- How do we balance our focus on interactions and components?

- What advantages and challenges lend themselves to virtual design environments that enable the continuous design of systems via geographically-distributed design teams?
- Will the availability of real world complex system design problems prevent researchers from properly validating their research methods?

A.5 Interface of Design and Manufacturing

The interplay between designing innovative products and economically and efficiently manufacturing those products is an important, well-known area of research, as well as a daily concern for commerce. While much attention has focused on this area, the participants identified the need for continuing the support of research in this area.

Progress in this area requires researchers in the design community to interface more effectively with manufacturing technology. Similarly, design researchers need to work more closely with industry professionals to understand and address the real issues faced by these professionals. In this way the community can begin to develop methods needed to support the integration of design and manufacturing. For instance, we need to embed cost and manufacturing considerations into the design exploration of structures and materials. Methods are needed that guide, constrain, and assist the designer to use specific manufacturing capability.

There is a need to bridge between design exploration and design optimization to obtain solutions that are near-manufacturable solutions. For instance, manufacture of designs that results from topology optimization should be considered. Participants noted that translating the results from topology optimization into CAD representations is difficult but necessary to integrate with manufacturing.

One source of design-to-manufacture guidelines is the use of previous designs. This is common practice in industry, but is an under-used source of information for researchers. Thus the participants wondered how we can use legacy manufacturing data to support design decisions. How should we use the history of previous designs in assessing manufacturability and to create manufacturing plans?

Training engineers to consider manufacturing equally with other performance analyses is important to wide dissemination of methods that result from research. Thus, an important component of such research is the understanding of how to employ design for manufacturing techniques in design classes. Similarly, specifying tolerances is a routine part of CAD modeling, but methods that base tolerances on design performance are not covered in most design courses. Thus, we need to develop methods for teaching design tolerancing.

A.5.1 Design and Additive Manufacturing

The recent widespread availability of Additive Manufacturing, or 3D Printing, has raised renewed attention to the role of layer-based fabrication technologies in the design process. So-called Maker Spaces are proliferating, and the cornerstone of many of these fabrication centers is low-cost 3D Printers. Most users of such facilities are not experts. Many are not trained in the use of computer-aided design (CAD) systems, the source of most input geometry for 3D Printing. Thus, there is a need to develop easy-to-use CAD systems that are approachable by users of all capabilities. Likewise, the development of Design for Additive Manufacturing guidelines will increase usability of such systems.

The participants noted the lack of computational tools to support design for AM. For instance, given a CAD model, how can we simulate an AM process for fabricating the model? Did we actually manufacture the part we thought we did? Which design methods for, and representations of, multi-material designs are available? The answers to these questions will provide the support needed to increase the user base for Additive Manufacturing.

A.6 Hybrid Human/Machine Processes and Systems

The participants considered the role of automation, machine intelligence, and human action (and their hybrids) in systems, and, in particular, during the process of design. The possibility of such hybrid systems suggests the need for fundamental research investigating the roles of the human designer, and the human's interaction with automated design process, optimization, and machine intelligence. Design processes of the future might include:

- Human-machine design processes
- Combinations of human-automation-optimization-machine intelligence
- Intelligent machines evolving/adapting information, with a degree of learning
- Adaptive methods with intuitive, multimodal interfaces in the design loop to capture human input in designing (with feedback)

Research in scalable/adaptable information theory/modeling is needed to realize the potential of such hybrid systems.

A.7 Data-Driven and Computational Methods

The availability of more data (so-called big data) will inevitably affect the process of design. There are both direct sources (e.g., various forms of sensors) and indirect sources (e.g., consumer/demand monitoring through monitoring crowdsourcing/ crowdfunding websites). This calls for formalizing the translation of data to usable forms for design, and understanding the proper roles of data-driven and model-based approaches. When is it proper to use one or the other approach? How can the approaches be combined when appropriate? For data-driven methods, there is a need to manage data from different sources, and combining such data requires a model of the context of the different sources. Thus, understanding and formal modeling of data context is another interesting research topic.

This area of research can benefit from existing bodies of knowledge in several areas, including:

- Multi-agent systems
- Machine Learning
- XML and other context modeling methods
- Data-driven formal models (econometrics, computational social sciences, etc.)

B. VERIFICATION AND VALIDATION (V&V) AND METHODOLOGY

B.0 Introduction

The discussions considered four key questions:

1. How do you judge “quality” “rightness” “better” “completeness” in papers or other works you review in your area?
2. What do you call the process that ensures that quality, etc., i.e., how do you describe it in your work domain? Separate internal consistency and outside/real world validity.
3. What are the limits of what’s feasible in terms of V&V? Is there anything we can do (or should do) to standardize the process?
4. How do you identify gaps in the literature/decide what research to do next?

Over the course of the discussions, several key themes emerged and became the basis of the next round of discussions. While the community is overall excited about the current research topics being pursued and continuous progress being made in how we conduct research, there was a general sense that the level of research quality needs to be improved. There was also a lot of confusion about the difference between doing V&V on the research approach (i.e., how research was conducted) versus the methods that are applied to the output of the research.

In general, the participants believe that researchers are currently overly incentivized to ALWAYS pursue new/novel research projects at the expense of spending the time or resources (or securing the funding) needed to fully leverage the existing research effort and continue maturing existing concepts/methods. In addition, there is a feeling that researchers are not working effectively as a community (i.e., not citing each other enough, not talking to each other enough, not being mutually critical to each other enough).

In the remainder of the discussions, the participants focused on how the incentive system could be changed to motivate: a) a more collaborative approach to advancement of the state of research in our field, and b) to improve the scientific validity of the research coming out of this community. This could take the form of NSF (or journals) enforcing V&V standards, new funding mechanisms focused on advancing/incrementally building on existing work, and access to education on some of the newer research approaches that are beginning to be used in this community (e.g., coming from other established research traditions).

After the initial discussion with groups on the topics described above, the discussion was narrowed to the areas described below. The objective of the discussion shifted to identifying "actions" that can be taken.

B.1 Opportunities for increasing sharing of data, models and benchmarks.

Part of the lack of community culture is believed to be an inability to share useful research items. If sharing was facilitated, other objectives associated with the creation of a "common good" culture could be more easily created. The following basic questions were explored with the groups:

- What can/should be shared: raw data, model implementations, benchmarking data sets, benchmark problems, compiled models (virtual machine), case study reports, training materials, survey questions, searchable list of who is doing what, design problems
- Standardization (could be either author regulated or repository enforced): content, data representation
- Incentives: need to develop a way to cite code or data in publications, include in tenure cases, can NSF data sharing requirements be expanded to include other artifacts such as: documentation and training materials, journals requiring (as opposed to supporting optional supplementary materials) posting of data and/or models (when possible, see issues below)
- Issues raised:
    - Funding for infrastructure and support
    - Length of support (viable "support until" dates) – supporting forever is not practical (what happens after all the students who worked on the "model" are gone, who supports then?)
    - The community must value work that proposes to use existing data/models. What is the mechanism for this?
    - Authorization to release data is not always practical (confidential, ITAR, IRB, etc.); how are exceptions to "required" sharing assessed and granted?

B.2 A need to value replication and extensions of existing work

The workshop participants felt that they could be doing "better" research if the incentive system allowed them to do more work on a particular project. The content of the "more work" varied by kind of research. For some that would mean spending more time on the nitty gritty tough problems, running more test cases, conducting additional analysis of existing data, or replicating preliminary results in other settings to test the extent of generalizability. The discussions explored a number of ways to enable the above kinds of follow-on work.

- Use early stage graduate students to replicate existing results from other groups. The NSF could support first-semester graduate students to replicate a curated set of community results. This would serve to a) train graduate students in the process of conducting a research study and b) add validity/credibility to the common body of knowledge. It would be important to share the results of these efforts, e.g., at an annual replication conference. Depending on the nature of the result to be replicated, this might fit equally well into a undergraduate capstone project.
- Create a special funding line (i.e., separate from the pool of unsolicited proposals, but still within ESD/SYS) to support work that either leverages existing data to learn new insights (e.g., same data, new theory) or replicates a past study in a new setting. While these types of study would have a high likelihood of generating new knowledge, they would be unlikely to review well through the normal peer-review process. These could be administered as extensions to traditional grants, or separately.
- There was discussion about whether there is a need for “facility-style” funding within the design community. While, the participants do not see a need for infrastructure per se, there are some core research questions that cannot be addressed without sustained systematic data collection in real organizations. The participants see a close analogy to the way the space science community funds Social Behavioral observatories that feed data to the community for decades to come, or the large panel surveys conducted in Social Behavioral and Economic Sciences. In both cases, investigators can write proposals to use the data. How to select the team to conduct the study and organizational setting for the research are obviously critical questions for the community, and would need to be addressed.

The outputs of such work would likely lead to a different style of paper than is traditional in our field. In addition to creating appropriate funding mechanisms, the participants felt that there is a need to encourage journals to fund “replication” style research, or at least to generate new criteria for quality of research of this type.

B.3 Lost discussion and negative results

In the past, many journals included active discussion forums to which researchers could write and submit discussions (letters) pertaining to papers published in the journal. Today, relatively few engineering journals support this type of public publication correspondence. The loss of this mechanism may be due to the rise of the internet blogging and discussion forums, or simply to the current focus on paper count metrics, e.g., citation counts that incentivize university faculty to spend their time and effort on new paper generation versus the discussion of papers by others.

Ideas discussed on the topic of Lost Discussion Sections of Journals include:

- Do we need to revive the "letters" section of journals?
- This could be a venue for replication of results.
- One idea is to make pre-prints of papers available to the community for comment, editorial generation, and replication prior to initial publication. This would potentially allow other authors to create content that would be published along with the original paper.
- Need to find a mechanism by which contributors of discussion/editorial/supplementary materials can obtain appropriate publication credit for their efforts.

B.4 Practitioner Translation:

Much of the original modeling/methodology/process development taking place in the design community is not being adopted by the practitioners (now or ever). Why is this? While there is no expectation that everything researchers do will find its way to practitioners, the participants are disturbed by the apparently very small fraction that is used. Suggestions to address this issue are:

- Form a "D-Corps" program to do practitioner discovery (what practitioners need, find out who the appropriate practitioners are). This could be similar to the NSF I-Corps program, but without company formation as the desired outcome.
- Could some of the "sharing" issues raised earlier facilitate adoption by practitioners?
- Should "technology readiness levels" be created to assign to researcher's work?

B.5 Raising Quality:

- Shared formalization on methods – common best practice
- Shared formalization on approaches – classes on design research methods
- Metrics of merit
- Create a map of all the existing work (need to define the landscape) and keep it up to date. Use history of DETC conference sessions to guide the structure of this (as a first draft).

C. SUMMARY REPORT OF THE EDUCATION BREAKOUT SESSIONS

C.0 Introduction

From the discussions that took place it is evident that the community has made great strides in some aspects while in others more work needs to be done. This is to be expected in these two relatively new fields of engineering; design & systems. The discussion held may be characterized as being frank, collegial, open, honest, and at times passionate. These are indicators of a vibrant and healthy community.

Below the main talking points from the breakout sessions are summarized. More in depth summaries from each facilitator are attached as appendices to this document.

Barriers to Design Education: the community needs to better promote the acceptance of design education as critical and integral to an engineering education. Ways to address faculty's lack of design experiences need to be identified. A lexicon of design is critical to help promote design education and to facilitate the teaching and learning of design.

Capstone Design Projects: should a "real-world" experience be the object? Is that the best learning environment? Should projects be industry sponsored? Should industry be involved? What is an interdisciplinary project and how should they be managed and assessed? What constitute a "good" design project? How should design projects be assessed?

Common Cores in Engineering Design and Systems Engineering. A standard body of knowledge or common core needs to be identified at both the graduate and undergraduate levels in engineering design and in systems engineering. Two topics to be included in these cores are: problem definition and model formulation. At the graduate level in engineering design there was consensus on some topics for inclusion in a common core: design theory, numerical optimization, verification & validation methods for empirical studies, creativity, statistics, teaming, social & behavioral sciences, advanced and additive manufacturing processes, programming, and leadership. Along with common cores, the community needs repositories of pedagogy, assessment tools, project management tools, etc. to facilitate the sharing and promotion of best practices in engineering design and systems engineering education.

Assessing Design Learning. The community needs to identify and promote best practices for assessing the learning of design knowledge. This will help to promote the inclusion of design theory & methodology within engineering education as well engineering design as a valid and thriving research community.

Circle of Design Workshop Reflections

C.1 Subgroup 1

This section summarizes the discussions on engineering design and systems education, specifically the discussions related to the body of knowledge that is defined by engineering design and systems. Several unsolved problems were presented, including limited availability of shared course materials. In particular, capstone design project results are readily available, but few if any references are available that share the sometimes difficult steps along the way from problem definition to final solution, and the pedagogy for helping students take those steps and learn how to apply them to future problems.

Another problem identified by the group discussions was the continuing lack of a commonly agreed upon body of knowledge that constitutes "systems", "engineering design" or any combination or permutation of those terms. After several groups' brainstorming and discussion, it did seem that there was some consensus around the idea that *model formulation* *skills* are at the heart of what engineering systems design students should know. Optimization was the highest ranked topic, followed by linear programming, decision analysis, and statistics. Other topics include computer aided design (AD), engineering economy, MBSE, uncertainty methods, sustainability, concept generation, complexity and collaborative design methods.

The main point is that our students should be *domain experts* in modelling how the components of a system integrate and function together, in order to predict and control the behavior of the system. This is in contrast to domain knowledge about a specific physical element, such as material properties, fluid dynamics equations, or stress/strain relations. "Systems thinking" and "design philosophy" were viewed to be important and were also discussed at length, but there was no consensus as to what specific tools or topics they would include.

A larger unresolved issue is whether "systems" should be taught as a separate and distinct body of knowledge, and even if it should be taught at all. If taught, what is the ideal time in a student's education for doing so? Some believe that it should be taught as a separate course (or courses), while others believe it should be integrated throughout the curriculum in a variety of courses, ranging from freshman to senior year, and on through graduate school.

There appears to be a need for development of a standard body of knowledge in model formulation. At present, it is taught primarily through ad hoc methods when teaching specific courses or model types, such as capstone senior design, constrained optimization, linear programming, decision analysis, etc. The student learns through an apprentice-type approach by engaging with the instructor in formulating models, but there appears to be no commonly agreed upon method for doing so. The community would benefit greatly by having such a method.

C.2 Subgroup 2

The workshop identified several interesting perspectives on design education and opportunities for development. The discussions indicated that design education has advanced considerably in the past decade. Many programs have integrated authentic experiences into their design curriculum. These experiences often involve engaging industry in sponsoring "real world" projects. Questions arise: (1) Do industry-sponsored projects reflect the "real world" just because they are industry sponsored? (2) Does real-world or industry sponsorship lead to better engineering design education? (3) How do we know?

There is clearly an opportunity to gather information about different projects used to support design education. An action item is to collect information from different engineering programs about their engagement in authentic experiences in support of design education. Topics to consider are (1) Demographics of sponsors (ex. Large company to small start-up, NGOs, competitions, etc.); (2) Relationships of sponsors to university; (3) Scope of projects; (4) Refinement level of definition of problems posed; (5) Sponsors resource commitments (time, money, etc.); (6) Duration of engagement. (7) Outcomes of projects when completed.

There is also an opportunity to explore appropriate assessment instruments relating the authentic experience to design learning. An action item is for the community to examine how we can assess appropriate projects pre- and post-engagement.

It also was stressed the importance of engaging “interdisciplinary” in design education. Interdisciplinary teams have been interpreted widely. Most viewed this as engagement of students from different engineering majors. Others looked even more broadly to inclusion of students from business, sciences and art, among others. All recognized the challenges in engaging in interdisciplinary teams. Are the members of the team from different departments or is the class also taught in an interdisciplinary context? An action item is for the community to gather information about the current state of “interdisciplinary” in design education in engineering programs. From this identify challenges and best practices for implementing more engaging interdisciplinary opportunities in design education.

There was also considerable discussion about the importance of reflection in design education. The engagement in authentic experiences is intended to enhance the students’ learning of design theory and methods. What efforts are made to ensure that students are relating their experience to the more formal education? The experiential education community has developed many techniques for guided reflection (they call processing). An action item is for the engineering design community to formulate best practices for promoting reflection to enhance the learning.

Considerable discussion involved the importance in identifying common foundations in design education to enhance and build upon them. Foundations identified included: Uncertainty and decision-making; Game theory and teaming; Optimization; Behavioral Science; Creative Thinking. An action item would be for the design education community to identify relational topics in these foundations to build up into useful educational paradigms in design education from formal learning to application.

Another topic of considerable discussion involved the socialization of engineering students in establishing an identity of design. In other words, what characteristics are we trying to develop in our students? These identity characteristics include: curiosity, creativity, entrepreneurial thinking, and social awareness, the ability to think at varying levels of abstraction, ethics, integrity, mutual respect, resilience, and grit. An action item is for the design education community to examine the desired identity of engineering designers, develop educational opportunities for students to develop them, and formulate methods for adequately assessing them.

C.3 Subgroup 3
What should be taught in Design?

Discussion Prompts: Discussions were generated by several different prompts. These included: what should constitute a "common core" in design education at the undergraduate level?, what should constitute a "common core" in design education at the graduate level?, what design content should be taught to practicing engineers?, what should be taught to future design researchers?, how can design be taught in an online asynchronous fashion?, what are the common cross-cutting themes across K-12, undergraduate, and graduate design education?, and how do we, the faculty, assess student learning of design content?

***Undergraduate Common Core in Design**:* It is very evident, from 3 different groups that were asked to address this topic, that there is no consensus what so ever in the community as to what should constitute a common core in undergraduate design education. Nevertheless, there is consensus that undergraduate students must have at least one meaningful team design experience, such as a traditional engineering capstone design project, in which to implement the design knowledge they have gained. It was clear from the discussion that there is a wide variety of thoughts and beliefs as to what should and what should not be taught to undergraduate engineering students with respect to design.

***Graduate Common Core in Design**:* At the graduate level there was much more agreement as to what should constitute a common core in graduate design education for engineers. There was consensus on the following topics: design theory, numerical optimization, verification & validation methods for empirical studies, creativity, statistics, teaming, social & behavioral sciences, advanced and additive manufacturing processes, programming, and leadership.

***Design for Future Researchers**:* Discussions on this topic reached consensus that programming skills, verification & validation methods for empirical studies, and statistics are topics that should be introduced at the undergraduate level and reinforced at the graduate level to prepare graduate students to conduct research in engineering design.

***Online & Asynchronous Teaching of Design**:* The discussions on this topic revealed that the community believes this to be an open research question that the community should be addressing, now. University education and pedagogy are rapidly changing and the effective and efficient teaching of design online and in asynchronous environments is fast becoming necessary. Research needs to be done to identify and when necessary create new pedagogy for this learning model.

Cross-Cutting Themes in Design Education*:* A few high level themes were identified by the participants. These include: social & behavioral sciences, creativity, uncertainty, decision making, modeling & analysis, and programming.

Assessing the Learning of Design*:* The discussions on this topic revealed that the community believes this to be an open research question that the community should be addressing now. University education and pedagogy are rapidly changing and the effective and efficient assessing of the learning of design is, regrettably, still an open research question. Rigorous design education necessitates having metrics, rubrics, etc. that efficiently and effectively assess the student's learning of design. Research needs to be done to identify and when necessary create new tools for assessing design learning.

C.4 Subgroup 4

What should be taught in Design?

Teaching design: There are two strands of thinking on how design should be taught. They are: a) aspects of design should be incorporated in the methods courses such as Optimization and others and b) design should be taught through explicit courses on Design such as the Capstone design course. Pedagogy of Design course cannot be one where there is a right and wrong solution rather on the existence of multiple possible solutions. Students should be challenged with open projects to understand the multiplicity of solutions. Teaching framing of design problem is a very important component of design education. Student should be able to understand that they cannot know everything in solving a design problems but should know where to find the knowledge in people or other resources

There is a necessity to provide framework and standardized curriculum for design courses in the undergraduate and graduate courses. These courses should identify the methods and processes that a student of design needs to know. For example, there were comments about the lack of optimization course for mechanical engineering undergraduate students leading to the need for teaching them about it in the design course.

Approaching from a scientific perspective, we need to look for regularities across design experiences and teach them. Design is not unified body of knowledge making it hard to put in a box. There may be contextual differences in the regularities observed and they may have to highlighted. Design in the small and design in the large may have only some overlapping regularities and we need to distinguish the patterns for use in education. How do we teach them about validation of design from different perspectives? Do we teach validations of models and methods?

For example, social aspects of design vary with cultures and how de teach those aspects of design or should we teach them about it at all? Is design knowledge independent of culture and is practice independent of culture? What does it mean to teach such differences to students in their ability to think and do design? Are the faculty prepared well enough to teach design and problem solving?

A major problem faced in the teaching of design non –uniform terminology across disciplines. For example the terms decision variable in decision theory and parameters in Optimization are the same but use different words. The need to overcome these differences in literature becomes hard in teaching design that includes multiple methods and models.

Assessment of student learning*:* One approach is to understand what the employer would want from person training in design and evaluate the student capabilities. What are the basic understandings that we expect of them as a designer? The necessity for measurement of student understanding of designing is an important topic to be addressed.

Teaching about the study of design: Teaching about the study of design would require experience in designing. Graduate student may or may not have that experience in designing. Should there be model to experience design as part of a design PhD? How do develop a good understanding of methodology, methods and approaches in science and design that we need to teach as background in the study of design. If there were to be qualifiers for graduate students, what would it cover?

In the study of design there was some consensus that there is necessity to bring human aspects of design, organizational theory, and Design analysis, why things fail and what research methods should we borrow from other disciplines to cover the range of issues in design. A course on design methodology for graduate students was suggested but no such curriculum exits as of now.

Many participants said that they do not have time to teach the study of design or design beyond the scope of the PhD thesis as the funding requirements and the necessity to graduate them does not leave time for explorations beyond learning the methods for specific thesis task. This again raised the issue of the faculty themselves not having the training in Research methods beyond their own narrow disciplines.

What are the obstacles students faces in thinking about Design?

Students come from multiple backgrounds leading the problem of creating single structure for the design course. The question whether it is possible to teach design and the body of design knowledge independent of culture. Further, how do we adapt teaching as different cultures respond to different styles of teaching? Approaching design with the diversity of students affects the student abilities to deal with design thinking.

An important impediment is that students want to learn tools than understand the logic of the methods. The issue of how to map problems to methods and their relationships to tools in teaching is an important obstacle due to the tendency of students to look for cookbook approaches.

One of the obstacles is that most Capstone design courses are a single semester leading to problems where the senior students do not have enough skills to perform design from their existing training so they do not get the full experience of designing. An exemplar implementation at Howard University is to combine students who are freshman with students from higher levels including graduate students in the project. This approach allows for mentoring across student levels. Further, the student experience over the years covers entire design experience. The necessity to inculcate the notion of respect for other disciplines was raised and that cross disciplinary experience could be a valuable way to achieve this goal?

What is the Difference between Engineering Design and Systems engineering?

In general people agreed that the difference between Engineering Design and Systems engineering is quite nominal especially if we start adding thing like design for X making engineering design a systems design. In some sense engineering design may seem to focus just on the product definition but Systems engineering is directed at interactions of the product design to other aspects that are critical to product manufacturing, functioning and use in a given context. There were some differences of opinion on the distinction between Systems engineering and engineering design from a methods point of view. Engineering design does not consider people but Systems engineering does include people.

Other issues: Not many agencies are funding design research and the focus on design is not something that is accepted in many departments. Junior faculty members will take risks and will stick to what is useful from their perspective. Unless there is concerted effort in promoting design and the value of design it would present an obstacle for propagating design studies and design courses in a curriculum beyond current efforts by individual faculty and schools.

There was also a sense that study of design into too many areas such creativity, innovation and other aspects of design is diluting the ability to promote design as a rigorous Scientific activity similar to the sciences.

D. **SUMMARY AND CONCLUDING REMARKS**

The workshop demonstrated the eagerness of the participants to come together as a community and to address these fundamental questions that will drive the directions of research and education in the design and systems engineering fields. Interestingly, the merging of these two communities showed the synergies existing between them, and the broadening of the engineering design community to tackle systems, expanding its domain beyond the considerations of a product.

One interesting point that was raised in the Verification and Validation and Methodology sessions is the need for the community to be more cohesive, to work better and more effectively as a community. This issue was brought out in previous meetings at recent annual ASME International Design Engineering Technical Conferences (IDETCs), and the general consensus is that meeting once a year in a conference is not sufficient to bring the community together and to encourage researchers to collaborate. We thank NSF for the opportunity to bring us together an additional time during the year and hope these activities will continue since they are extremely important for the community. We believe also that creating larger multi-PI research topics will further strengthen collaboration and generation of new ideas, new methods, and new science to benefit all.