Workshop Summary

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https://engineering.purdue.edu/ME/EDSE

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1. Introduction

Engineering Design and Systems Engineering (EDSE) research focuses on establishing fundamental understanding of how engineers work individually, or as part of large organizations, to create innovations ranging from products to complex systems. EDSE research has had significant impact on a wide range of professions, including, designers, analysts, manufacturers, systems engineers, and policy makers. The outcomes of EDSE research have enabled designers to reduce the environmental impact of their products, helped companies in designing products customized for their customers, and supported systems engineers in improving the effectiveness of their processes. The outcomes have enabled engineers to improve the quality of automobiles and aircrafts, supported materials designers to design novel engineered materials, and helped policy makers in designing policies relating to engineered systems.

The focus of the workshop is on the opportunities and research needs for engineering design and systems engineering (EDSE) in the emerging workplace and society. The key driving questions for the workshop were:

- How are emerging machine learning and artificial intelligence technologies changing the workplace and the society, and what are the new opportunities for EDSE research?
- How can EDSE research make sustained impact on diverse application domains, such as manufacturing, transportation, and smart and connected communities?

The NSF workshop attracted over 100 leading scholars from top engineering schools across the country, along with program directors from NSF and DARPA. The workshop agenda consists of plenary talks, a panel discussion, short presentations (lightning talks), brainstorming sessions, and report-outs on the discussions. This workshop engaged EDSE researchers, industry participants, and foundational scientists in the collective thinking of the future of EDSE. We anticipate that these interdisciplinary synergies will strengthen our understanding of key research issues and foster research collaborations across disciplines and universities.

1.1 Overall framework

The <u>overall objective</u> of this workshop was to develop and articulate research issues and methodologies in engineering design and systems engineering (EDSE) for high impact in the emerging workplace and society. Key questions and the topics for discussion related to each of the workshop objectives were as follows.

1. To identify new opportunities, needs, and research challenges for EDSE in the emerging workplace and society

- How are emerging machine learning and artificial intelligence technologies changing the workplace and the society? What are the new opportunities created for EDSE research?
- What is the potential role for EDSE research in the future of work, smart and connected communities, and smart transportation?
- What are the common and unique design-related challenges across these application domains?
- Which design and systems engineering approaches are these application domains currently using? How can EDSE research improve these practices? What is the potential for impact?

2. To identify ways to maximize the individual and collective impact of the EDSE research community.

- What are the best research practices that could enable the community to build on each other's work?
- What can EDSE researchers leverage from recent methodological developments in other scientific disciplines such as psychology, behavioral economics, and cognitive science?
- How can EDSE researchers enhance validity, generalizability, transferability, representativeness, and reproducibility of their efforts?
- How can common fallacies in designing experiments be avoided?
- How can reporting of scientific results in EDSE publications be enhanced?

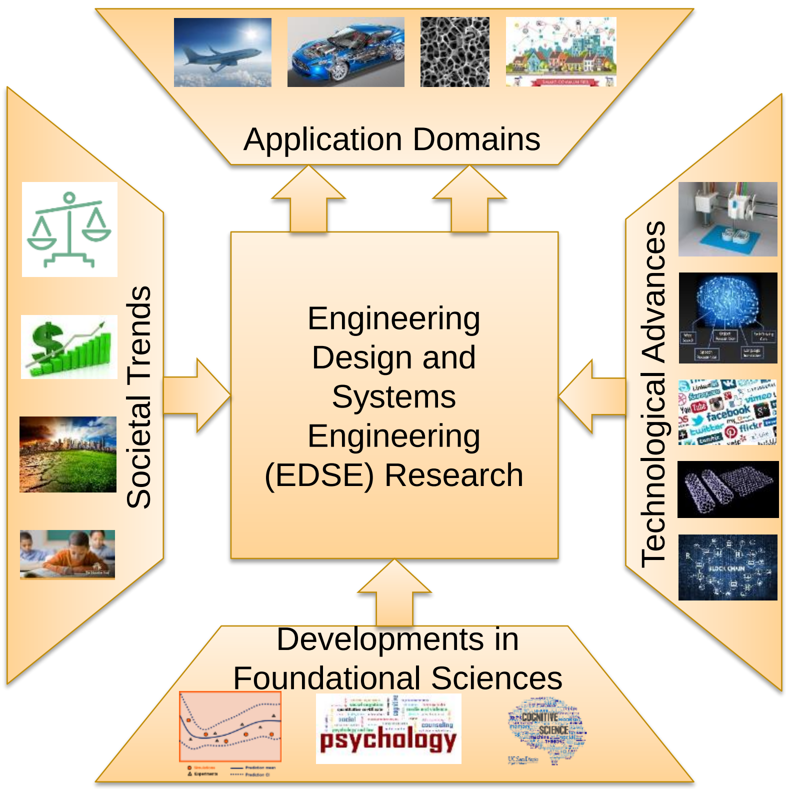

Figure 1 – Overall Framework of the Workshop

1.2 Workshop outline

The workshop was structured as follows:

- Three Keynotes
  - Investing in US Innovation Ecosystem - The Case for a National Manufacturing Foundation; Dr. Sridhar Kota (University of Michigan)
  - Computational models for creative design: curiosity, novelty, and surprise; Dr. Mary Lou Maher (UNC Charlotte)
  - Design Beyond Imagination; Dr. Jan Vandenbrande (DARPA)
- Three Short talks
  - Dr. Richard Malak
  - Dr. Shirley Dyke

    - Dr. James Allison
- 17 Lightning talks
    - Dr. Kate Fu
    - Dr. George Hazelrigg
    - Dr. James Kai
    - Dr. Julian Norato
    - Dr. Bryony DuPont
    - Mr. Matt Law (for Dr. Guy Hoffman)
    - Dr. Mark Fuge
    - Dr. Zoe Szajnfarber
    - Dr. Erica Gralla
    - Dr. Alejandro Salado
    - Dr. Kathryn Jablokow
    - Dr. Leifur Leifsson
    - Dr. Paul Grogan
    - Dr. Shikui Chen
    - Dr. Chris Mccomb
    - Dr. Daniel Silva
    - Dr. Erin MacDonald
- NSF program director's talk and office hours
- Three breakout sessions focused on the following themes:
    - Opportunities created by emerging technology, changing workplace and society
    - Needs and challenges in diverse application domains
    - Strategies for maximizing collective impact

The following sections summarize the discussion in the breakout sessions.

2. Opportunities created by emerging technology, changing workplace and society

In the first breakout session, the workshop participants were prompted with the following questions: (a) What are emergent technological changes that might drive change? (b) How might these technologies change the world around us? (c) How might the technologies change the nature of engineering work? (d) How might the technologies change the next generation of products/systems, and/or the way people design/create products/systems? (e) How are these technologies likely to influence design practice, research, and education? (f) What changes will these technologies bring to policy, to government, to privacy, security, social welfare, sustainability, etc.? (g) How might we design society to be resilient to technological shocks? (h) How might we predict the effect that AI/ML will have, when applied to mass scales or more widely beyond research-scale prototypes?

The specific technologies discussed in the first set of breakout sessions included (i) Artificial Intelligence and Machine Learning, (ii) Automation, (iii) Additive Manufacturing, and (iv) Internet of Things. The discussion during this breakout session is summarized in the following sections. Key points are listed in Table 1.

Table 1 - Summary of technological trends, and resulting opportunities for EDSE research

	Technological trends	Opportunities for EDSE research
Artificial Intelligence and Machine Learning	• Commoditization of the hardware and software • Advances in software capabilities such as probabilistic programming languages, privacy preserving algorithms • Better predictive capabilities	• Physics-Informed AI/ML • Reliability / uncertainty quantification / design optimization • Designing AI/ML/data into products • Automation of design activities • Assisting human designers • Addressing verification and validation challenges
Automation	• Changing nature of work • Evolving work environment • Different needs for training • New models of collaboration within and outside the organization	• Distributed work • Crowdsourcing • Adapting to different work contexts • Education
Additive Manufacturing	• New types of designs • Democratization of manufacturing • Shortened the lead time of products • Changes in supply chains	• Better design representations to support design for AM • Incorporating different physics and variability in topology optimization • Increasing the adoption of topology optimization in industry • Understanding the effects on supply chains.
Internet of Things	• Internet connected devices • Data collection through sensors	• Security, privacy and trust • Product design leveraging data generated form IoT systems

2.1 Artificial Intelligence and Machine Learning

2.1.1 Technology Trends

The rapid growth of artificial intelligence (AI) and machine learning (ML) technologies is fueled by commoditization of the hardware, which improves access and reduces cost. There is easier access to computational infrastructure both hardware and software codes. Edge computing is playing an increasing role in product-level AI. There is also an exponential expansion of larger and larger bandwidths and storage. The commoditization of hardware is supplemented by advances in software capabilities, including probabilistic programming languages and other capable languages (e.g., Julia), privacy-preserving algorithms and other Distributed ML algorithms. These developments have enabled fundamental scientific advances in AI and ML, causal inference and neuroscience, resulting in better predictive capabilities that could affect decision making under uncertainty.

2.1.2 Opportunities for EDSE Research

AI/ML technologies lead to several possible opportunities such as the ability to deal with systems of much higher complexity than is current practical, opportunities to "discover the unimaginable" especially with models and data streams that we cannot or will not look into normally, 22nd century educational programs, and supporting human engineers and teams. During the breakout session, the workshop participants highlighted the following key areas that present new opportunities for EDSE research: (1) physics-informed AI/ML, (2) Reliability / uncertainty quantification / design optimization, (3) designing AI/ML into products, (4) AI-assisted automation of design activities, (5) assisting human designers, and (6) addressing V&V challenges for AI-based systems.

1. *Physics-Informed AI/ML*

Existing design methods are primarily driven by physics-based models and computational tools. There is an increasing use of and data-driven machine learning techniques to support design. The workshop participants noted that there is significant benefit to be gained by combining engineering models with ML techniques, specifically physics-based AI/ML and embedding engineering models into emerging ML models. For example, algorithms that constrain the machine learning models using physics knowledge are likely to extrapolate better with trained with limited data. Physics-informed AI/ML can improve the efficiency of statistical learning and inference tasks. Such integrated models offer an alternative to metamodeling which may scale better to high dimensional settings.

There was a discussion on the important role of explainability in AI. Explainability is important to assess whether the models are overfitting or actually capturing the underlying process. There is a need to know more about how to explain the results that AI/ML algorithms produce. If designers don't know why they are getting the results that they are, then they can't push to new regions. Accuracy of models, although important, does not necessarily lead to the best design, or a more profitable one. There is a need to understand the consequences of not understanding these algorithms.

2. *Reliability / uncertainty quantification / design optimization*

Uncertainty quantification is an important ingredient of design optimization and reliability-based design. Deep learning techniques can be used for dimensionality reduction. These techniques can be used for temporal / dynamic modeling of reliability. The emerging technologies present new opportunities for improving predictive maintenance through better utilization of data for operational performance, thereby informing engineering design and redesign.

3. *Designing AI/ML into products*

AI/ML-based techniques are increasingly being used in smart consumer products. However, much of the data analysis is currently carried out manually. There is significant opportunity to develop systematic design methods for designing AI/ML into smart products that map data into informed decisions. There are also opportunities for using AI to develop digital twins that can automate the generation of synthetic data. There are new opportunities for designing AI-enabled products and systems to adapt to humans, and to assist them. For example, AI can be used to tailor its interface to different users. It can learn individual differences among users. There is potential for new types of products such as products that use AI for training, and for explicitly supporting human learning process.

The workshop attendees discussed several research challenges that need to be overcome. For example, there is significant variance in HCI experiments. There was a discussion on the need for educating the users. Following questions were raised: Do people need to understand how ML/AI works in order to use it? What are the consequences of not fundamentally understanding the math of the algorithms when they are implemented? Do we need an education on what AI can and can't do, when to rely on it and not?

4. *AI-assisted automation of design activities*

The trend of leveraging AI to automate engineering design activities started with expert-based systems. With the development of the next generation techniques, AI is being used for generative design. Commercial tools are available for generating geometric designs from loading and boundary conditions. There is opportunity to expand the scope of the generative design methods to a broader range of activities. An example of a potential future design automation system would be one that parses the requirements document using natural language processing, and determine functions, geometry, and materials that meet requirements.

There are several questions that emerged during the discussion: How much do we automate? How much do we learn? What kinds of metrics (Accuracy vs speed vs explainability) are important for us to consider in the context of design problems? How do we define outliers? In the context of reinforcement learning in resilient design, we don't have data/ supervised data and we won't have optimal design. How can a model learn from environment? How can ML/AI be used for targeting/ locating small problems? A lot of design situations don't have structured data; therefore, supervised learning/traditional models do not work very well. What are the alternatives?

5. *Assisting human designers*

A counter argument to completely automating engineering design is about the role of the human designer. Several questions were discussed during the breakout session, including: "What is the role of a designer if you can automate engineering design? Design is fundamentally a creative endeavor, but it is presently unclear how much and what aspects of that endeavors should or can be automated? What is left in that case? What should be left?" There was discussion about the dramatic changes in the roles of even established professions - i.e., doctors are becoming more as caregivers, and less as diagnostic tools. Engineers are perceived more as innovators and less as analysts.

In contrast to completely automating design activities, AI/ML technologies can be used to assist human designers in the creative design activities. The key question is: How can AI/ML supplement humans to support us and limit our weaknesses? Can AI/ML techniques be used to understand designer intent? How can AI/ML be used for retrieval of information from the past (e.g., lessons learned in industry, provided just in time) and for organizing knowledge (e.g., AI to help document lessons learned)? How can these technologies provide inspiration to the designers? What are opportunities to maintain human interaction? At what point do humans become obsolete? How does this change how humans are accounted for? There is an opportunity for identifying high-value areas in engineering design that could be complemented by AI/ML. These questions should be answered with a focus on the interaction between AI and an engineer. There is a need to be aware of what the interaction between the Engineer and AI and how can we shift the interaction such that we can avoid any downsides.

6. *Addressing V&V challenges*

The design of AI-enabled learning systems present novel verification and validation challenges. There is a need to understand what verification and validation mean in the age of AI/ML. For example, as systems learn after they are deployed, the verification tests carried out during the design process may no longer provide useful information. There is a need for new processes and methods for V&V for AI/ML based systems that explicitly account for trustworthiness of systems, and how do we verify properties of this system, implicit biases in the training process, and attacks on the system (e.g., side-channel attacks).

2.2 Automation: Changing Workplace and the Future of Work

2.2.1 Technology Trends

The emerging tools such as artificial intelligence (AI), virtual reality (VR), and distributed collaboration, new team organizations are enabling new approaches to design complex systems. The nature of work might change in the future in coordination with how our tools change. Examples include AI feedback and recommender systems, generative design tools, etc. There is a reduction of labor-intensive work and resultant increase in cognitive load. There is a need to design products and systems in a way that maximizes human satisfaction (e.g., automating dirty/dull/boring tasks, reserve enjoyable tasks for humans). There is an increasing trend towards working at higher level of abstraction, which comes with a risk of potentially losing essential skills.

In addition to the availability of tools, the environment that we are conducting our work will change in the future. One example given was the fact that more people may be conducting work in autonomous vehicles. These individuals will be working at different times of the day and in different environments. There is potential for technologies such as virtual reality (VR) and augmented reality (AR) to enable more complete experiences for virtual meetings and recordings. These technologies will make it easier to learn new skills at a potentially lower cost.

New technologies are enabling individuals to do more. Tasks that were previously accomplished by a team can now completed by a single individual (enabled by technology). Collaboration within organizations is evolving. Organizations are becoming more agile with smaller cross functional teams. There is also increase in collaboration with entities outside the organizational boundaries using innovation models such as crowdsourcing.

2.2.2 Opportunities for EDSE Research

Four key areas of research opportunities were discussed: (1) distributed work, (2) crowdsourcing, (3) adapting to different work contexts, and (4) engineering education.

1. Distributed work

With the emerging models of collaboration, there is a need for systematic methods for structuring problems and distributing/allocating the tasks to team members, particularly in engineering design tasks where the end goal is specified but the individual tasks/steps are not well identified. There is a need for measures of the success of collaboration. Open questions include (i) how to adapt when a person who is responsible for many tasks leaves, (ii) what stages of the design process are best suited for future collaboration, e.g., between domain experts vs. generalists, (iii) what are the best communication channels for agile organizations, and what tools are needed. There was discussion about the possible use of data and machine learning to understand the level of expertise of teams and individuals, which can enable accurate project estimation and planning.

2. Crowdsourcing

With the changes in technologies, there are questions about how to best integrate new models of employment / contract work within organizations. How do we identify experts within a crowd? Are different payment structures needed for crowdsourcing than for outsourcing? There are research issues related to the implications and payment structure for tasks carried out in non-traditional ways. There is a possibility of identity being lost with distributed labor. It is not clear whether identity is consistent with expertise.

3. Adapting to different work contexts

Different work contexts (e.g., hazardous environments) have different requirements from the design perspective. Some of the key questions discussed during the breakout include: “What is the technology (or EDSE methods) that can help address the identified work context? How do we deal with the mismatch between automation/new technology/current issues like sustainability outpacing the existing infrastructure (policies, physical structure, laws, etc.)? For example, more sustainable toilets use less water, however the low flows didn’t fit with the existing pipeline system (which needed higher flows to operate).”

4. Engineering Education

As the nature of work changes, the role of education also changes. There was discussion on the role of a university in the future of education, including the need to update undergraduate curriculum for automation/sustainability, the need to focus on problem solving and decision making, and making students comfortable with uncertainty and ambiguity. There was also a discussion on the future of the BS degree, where is seems the BS is becoming the new HS diploma and the MS is the new BS. There were comments on the reduction in credit hours for engineers. Many are at 128 credits. In the past, some took 150+ to get a BS degree. Issues with the removal of general education such as topics that teach morality or at the least the context of morality were discussed. One of the key questions during the discussion was - “are we training our students to be thinkers, or are we training them to be doers?”

2.3 Additive Manufacturing

2.3.1 Technology trends

Additive manufacturing influences the field of engineering design in several ways. First, it enables new types of designs that were not possible with traditional subtractive manufacturing processes. It enables manufacturing varied shapes and topologies, personalization of design. Additive manufacturing has enabled new type of metamaterials, and the applications are expanding to functional non-mechanical products such as electronics. Second, it has democratized the manufacturing process. Increasing number of people are able to make their own artifacts. Because of additive manufacturing, it is now financially viable to make artifacts with low-production-volume. Third, it has shortened the lead time of products from design to commercialization. Additive manufacturing has enabled faster iterations from design to testing/prototyping. There is now a closer collaboration between designers and manufacturing engineer. Fourth, the changes in designs, materials, and collaboration is changing the structure of supplier chains. Companies do not need to retain manufacturing capabilities in house. They can outsource tasks to small companies to get access to greater versatility in manufacturing process. Low cost of reconfiguration allows small companies to be more versatile (can jump from manufacturing one design to another in little time/cost). Additive manufacturing is also affecting maintenance and repairs. There is a reduced need for maintaining parts in the warehouse as parts can be printed on demand.

2.3.2 Opportunities for Design Research

There are several opportunities for research on design for additive manufacturing (AM). Current design for AM includes techniques for topology optimization, and design rules & heuristics. The current heuristics are highly dependent on the type of AM technology, materials, etc. There are significant gaps in addressing all relevant physics for different applications such as bone scaffold design and meta-materials. There are also significant challenges in incorporating variability of material properties and manufacturing process in the design.

Several areas of EDSE research opportunities were discussed. Existing design representations will have to change to better represent designs for AM. EDSE research can explore ways to increase the adoption of topology optimization as a design tool, and make it more accessible to a greater number of people outside the research community. There is potential for expanding the range of materials available to design engineered systems, for instance, for soft robotics. The full impact of additive manufacturing can only be realized through corresponding changes in the supply chains. EDSE research can investigate the system-level impact on designers, manufacturers, suppliers, and customers. The effects of the technology on the job market and the retraining needs of the manufacturing workforce needs to be investigated.

There is potential for investigating the impact on policy, government, privacy, security, social welfare, and sustainability. For example, polymer 3D printing brings challenges to sustainability (e.g., increased use of polymers and the challenge to the environment). Similarly, new challenges in security of health data associated with AM-manufactured medical devices need to be addressed.

2.4 Internet of Things

2.4.1 Technology trends

The ever-increasing trends of Internet-connected devices, use of sensors, and continuous collection of data from physical objects promise increased safety and reliability of products and systems. These technologies can be used for fault detection in complex systems, improved characterization and operation of complex systems through data collection (e.g., a bus collecting information on road condition).

2.4.2 Opportunities for Design Research

While there are several research issues relate to Internet of Things the breakout group discussion focused on two important areas: (i) security, privacy, and trust in IoT enabled products and systems, and (ii) product design leveraging data generated form IoT systems.

With the increasing capture of interactions with devices, there is a need to understand whether the intended design affordances are aligned with measured usage. Several questions about the security and privacy of data come up when designing such products and systems. For example, What data should be made public or not from networked sensors? What should be done with the data that is collected? How do we quantity the risk of making our data safe? How much should one pay for extra security? How can one evaluate a system and the risk of integrating them? Sensitive information (such as health data) and control of such information will be a key consideration of technology design and interaction. How can the change in tolerance threshold for privacy be measured? There is tradeoff between convenience and privacy. How does governmental regulation affect the scope of engineering work? How can engineering tools be developed to assess the difference in privacy levels? How can trust be established in IoT based systems? There is a need for holistic solutions for cybersecurity in the context of IoT, and their use in systematic engineering design processes. Similar to design for X, there is a need for policies and guidelines for creating IoT products. Ethical standards are needed for engineers developing IoT systems.

The questions related to designing products leveraging data generated form IoT systems include: How can products be improved through usage data? How can products be designer for connectivity? How can product performance be assessed based on user interaction with a device? There is a need for approaches for making decisions about an individual device design if connected and aggregated with other information in the networked system. Strategies for aggregation of multiple types of data and levels of quality are needed. How can designs provide transparency, convenience and performance to the users? How can Changes in user expectations for interactions with technology be assessed? How can technologies create value for the user, e.g., understand how people use energy?

3. Needs and challenges in diverse application domains

Each application domain is unique because of the nature of design problems, the knowledge available, the design methods used, etc. The second breakout session was focused on identifying unique needs and challenges of different application domains targeted by the EDSE research community. Within each domain, the workshop participants were asked to consider what is being designed, how the design is carried out, what the common design problems are, what methods are used, what the potential opportunities of design research are, etc. The following questions were posed to jump start the discussion:

1. What are the key design problems/challenges in the domain?
2. What are the standardized/well accepted design approaches in the application domain?
3. What are the research gaps and potential opportunities for EDSE research to have near-term and medium-term impact on the application domain?

The workshop participants were asked to self-select the groups based on the application areas they are interested in. The groups self-organized into three key application areas: (i) aerospace and defense systems, (ii) autonomous systems, and (iii) smart and connected health. This section summarizes the discussion during the breakout.

	Research opportunities
Aerospace and Defense Systems	• Digital engineering • Systems engineering for AI-based systems • Supporting systems evolution • Principles rather than process • Validation • Systems engineering testbeds • Integration with other stakeholders
Autonomous systems	• Human-machine interactions • Validation
Smart and connected health	• Personalized self-adaptive design • Design for human well being • Cybersecurity of system

3.1 Aerospace and Defense systems

1. *Digital engineering*

A central question in systems engineering of aerospace and defense systems is: “How to use computer models more effectively throughout the design (and use) process?” This includes everything from basic interoperability challenges and being able to share data more rapidly across technical analyses. The integration of systems modeling effort with analysis is still a challenge.

One of the key concepts in digital engineering is a digital twin. A key benefit of digital twins is rapid feedback from systems that are not prone to direct validation or incremental fielding (e.g., DevOps). There are research opportunities in understanding digital twins and the cost/benefit of using them throughout the system design lifecycle. Some of the questions include “What kinds of digital twins are useful in designing systems? How can we improve their usefulness?”

Current digital engineering tools and techniques lack support for early-stage systems design. For example, SysML was not designed for the early stage design. There is a need for new ontology/language for early stage systems design. The tools should ideally support seamless transition from early understanding of system with no or little physics-based modeling to later in the design process when physics-based models are available.

There is a need for probabilistic framing of design/systems problems. How do we wrap probabilities into the earliest portions of systems/design engineering? To continue to be relevant to practicing engineers, there is a need to be able to account for probabilities.

2. Systems engineering for AI-based systems

Current systems engineering tools are not appropriate for systems with a strong AI component. As mentioned earlier, verification and validation of AI-based is a challenge. For example, there is a lack of frameworks to certify systems with strong AI component. Similarly, there is a poor interface between software systems engineering and hardware systems engineering. Methods don't cross between the two fields. Interactions between human and machine elements introduces emergent unintended behavior which is difficult to mathematically capture. In addition to designing AI-based systems, there are opportunities in using emerging AI-based systems such as Alexa, Siri, Google Home, etc. to facilitate design.

3. Supporting system evolution

Developing aerospace and defense systems takes a very long time. They take a large amount of time to deploy, and the systems are in operation for a long period. There is significant technology evolution in such long periods of time. This not only leads to changes in components and subsystems, but also issues with the human capital to deal with such changes. A person who starts working on a project, typically does not see it finished. Therefore, knowledge transfer is one of the critical problems. There are significant opportunities for the EDSE community in establishing ways for adapting to change during the design process.

4. Principles rather than process

Systems engineering process is often seen as fixed from textbooks. Systems Engineering Vee, for example, is an established approach taught in every systems-engineering course. However, systems engineering methods need to be modified and adjusted based on the context, the situation, the system being designed, and other factors. To adapt to the uniqueness of each problem, systems engineers make on small changes to existing design processes rather than looking at what function these processes provide in the first place. In other words, current focus is on the prescriptive method ("what") rather than on the "why" of what we're doing.

There is a need for research, education, and practice of the underlying principles rather than merely following the process. EDSE community can focus on studying the intent behind the process and then to derive/design better ways of addressing that same need. This is because the intent and the principles behind the process remain the same, but the process itself is radically and rapidly changing.

5. *Validation*

Current validation studies within the EDSE community are primarily based on toy problems. Going towards more realistic systems is challenging because of the presence of too many confounding variables. It is difficult to get statistically significant results. There is a tension between being rigorous and achieving statistically significance, and the relevance to real systems. There is a need for deeper thought when organizing, presenting, and reviewing a validation study over what are the goals of doing the validation study, and whether validation results are useful.

6. Systems engineering testbeds

Continuing the discussion of validation, the participants highlighted the need for systems engineering testbeds, similar to testbeds adopted in other communities. There are several open questions about what a system engineering testbed could look like. What kinds of research reference models and organization models be used? How do we model the processes/people or do tests on them? Older models that the community can learn from include Ames Research Center / PHM group – FLEA, AFIT reference systems, CRM / common research model (from the computational fluid dynamics community).

There was discussion about whether to develop a common system testbed / research model that is agnostic across multiple fields. There is a need to identify potential research areas that aren't covered by a specific example. There are several challenges due to the different levels of fidelity needed for different researchers. This would a significant effort that could consume a lot of effort to build a very high-fidelity model. Some ideas to mitigate these challenges include using an open source model paradigm, developing high level models and then individual researchers building higher fidelity and deeper models off of the high-level models, evolving the models for specific needs at specific times, and publishing these new models in journals. Models of organization and behavior requires additional work to capture these.

7. Integrating with other stakeholders

The workshop participants discussed how to bring in other stakeholders effectively. Several questions were raised, including: How can we bring in cognitive scientists, machine learning science, data science, etc.? How do we take advantage of data science in systems engineering? How do our methods truly cross-cut, how do we compound our knowledge effectively? How do we bring SMEs from other areas to the table with the EDSE community?

8. Other opportunities

Several other issues were discussed during the breakout session, including decentralization, requirements/preferences, incentives, and mission engineering. SE has primarily been established as a centralized control mechanism. However, it does not well represent/manage multi-agent situations where multiple government agencies, multiple different autonomous groups, etc. are involved. Frameworks such as game theory can be used to understand how one design actor's objectives either align or conflict with other design actors' objectives.

There is an ongoing discussion about requirements vs. preferences within the EDSE community. Requirements are heavily used in this domain and, due to the complexity of the system, result in inefficiencies which has been documented in the SE literature. Requirements may close the door to preferences. There was discussion about whether and how expectations can be included in a contract. Is there value in freeing a contractor from constraints in the form of requirements?

There is an emerging field of mission engineering within the department of defense. Mission engineering problems are characterized by long-term impacts of decisions not only on the system but on the entire mission, and small design decisions having big implications throughout the mission lifecycle. The workshop participants agreed that there is a need for clarity in this field. The EDSE community can play a role in defining common languages and terms that can be shared.

3.2 Autonomous Systems

The discussion on the research needs for autonomous systems was focused on two key areas: (i) human-machine interactions, and (ii) specification of performance requirements and validation of autonomous systems.

1. Human-Machine Interactions

The key question in this area was "How do we design autonomous systems that properly interact with humans?" with the emphasis on long-term studies on human-machine interaction. The participants highlighted the need for interdisciplinary research projects that involve human, social, and psychological factors. There are several questions that EDSE community can tackle: (i) How might we design physical aspects of systems differently for autonomous operation compared to human operation? (ii) How to design effective communication with human users (system's performance, current status, machine's decision processes, etc.), (iii) how do human interactions with autonomous systems change across time scales (short-term interaction vs. long-term benefits), (iv) How can EDSE community incorporate the variables (e.g., human properties, levels of trust, etc.) that were traditionally neglected in engineering design research? (v) How can humans form, and manage the appropriate level of, trust with autonomous systems? (vi) What is the "right" level of human-machine interaction for a long term? (vii) What is the most effective mode of communication/interaction? (viii) How can we prevent the negative outcomes of human-machine interactions (e.g., social bubble formation and misinformation on social media)? There was also a discussion about design of machines that are human-like, and can perform tasks that humans are good at. Related questions include – (a) Can we design robots that can perform a wide variety of tasks similar to humans, such as maintenance tasks that humans can perform easily? (b) Is making those autonomous systems' interactions more "human-like" really our goal? Finally, there was discussion about the ethical and legal requirements/standards needed for designing and using autonomous systems. Questions include: Who is responsible/liable when something goes wrong? What kind of certification is needed for autonomous systems? How will liability be determined?

2. *Performance Requirements and Validation*

The challenges associated with clearly specifying performance requirements of autonomous systems and validating the systems against those performance requirements were discussed. Some of the questions include: How do you define the objective of an autonomous system? How do we design the process of evolving specifications? How can we refine objective functions to reflect real intent? It was highlighted that in some cases, the way some systems are tested provides a disincentive for implementing more effective control/autonomous systems. How might we influence revision of these test standards? What does a "test" need to look like?

There is a related need for fundamental research on performance evaluation of autonomous systems. How could we discover loopholes in intelligent autonomous systems? How do we validate hardware that can only be built once? How can we verify/certify that the system operates as intended, particularly in the case of complex integrated systems, or systems with adaptive intelligence? How can we define and implement safety bounds? How can the risk vs reward tradeoff be quantified? How do we deal with this for systems that are expensive/can only be built once? How can we enable large-scale, long-term testing before widespread deployment?

3.3 Smart and Connected Health

Engineering design and systems engineering methods are increasingly being used for healthcare related design problems. Several design methods have been used, including (i) *systems engineering* for identifying stakeholders and customers, (ii) *engineering optimization* for developing personalized prosthetics and products, and (iii) *mass production principles* for individual tailoring, designing for variety through mass scale means. While there are several commonalities between design for healthcare and other design problems, the details of medical problems are different than other domains. The breakout participants noted that there are recurring themes that we have fundamental principles and general methods, but it is difficult to tailor to the health-related problems.

Design for health care is fundamentally different from design of traditional products due to its unique challenges. For example, it is not always evident why a product fails happens. There is significant variability in patient physiology and usage. There is a need to consider entire lifecycle. The focus of design efforts cannot be just on the device but there is a need to also think about the maintenance of the follow-up and verification that the device works correctly. There are multiple stakeholders. There are various sources of errors including medical practitioners, and patient at different times.

Consideration of cost in the design process is also fundamentally different. Medical costs are different than traditional engineering costs as they don't necessary rely only on product manufacturing, but FDA Human trials and R&D can also influence cost. Traditional engineering objectives and algorithms don't necessarily translate to medical problems since medicine relies on objectives such as improving health outcomes without necessarily lowest cost possible. Finally, good technical solutions don't necessary solve culture/behavioral/economic issues.

In addition to these fundamental challenges which create opportunities for EDSE research, several research issues were identified:

1. *Personalized self-adaptive design*

There is a significant need for personalization, e.g., personalized prosthetics. Solutions we come up with can work for some patient groups but not others. Additionally, the physiology of the patients changes over time, e.g., changes in weight. The interaction of patients with the devices also changes over time. Therefore, in addition to personalizing the initial design, there is a need to continue adaptation for the patient. One of the questions from a design standpoint is -- how should we write and verify requirements for such self-adaptive systems.

2. *Design for human well being*

The design problems in healthcare space need to consider the overall well being of individuals. Design considerations for health, happiness, and safety need to be considered simultaneously with the goal of having product affordances to ensure the user is moving towards a healthier state. The products should be designed to detect signals as an early warning system, detecting bad behavior and addressing them prior to the behavior occurring. The design should also consider the societal and culture influences that can alter a person's behavior.

3. *Cyber security of system*

Cybersecurity is an important consideration for connected devices, particularly in the healthcare system. There are broader issue of privacy when designing products that collect and communicate information about a person's state of health or behavior. Data from individuals and could lead to public health decisions, take individual learning for network-wide value (similar to autonomous vehicle research).

Finally, the EDSE community can make a big impact by focusing on socio-technical solutions (instead of technical solutions alone) by working directly with medical professionals.

4. Strategies for maximizing collective impact

The third set of breakout groups was focused on identifying challenges and strategies for maximizing the collective impact of the EDSE community. The breakout groups were divided into three areas: (1) Computational Design, (2) Design Cognition, and (3) Systems Engineering. This section summarizes the discussion and key recommendations from the breakout groups.

4.1 Computational design

The key challenges discussed during the breakout session in computational design include (i) limited adoption of research products and outcomes beyond the lab, and (ii) challenges related to development of robust software tools within academic settings. The challenges related to translating the research software to commercial grade software include (a) lack of software development competencies in engineering students, (b) lack of funding for software development, and (c) lack of incentives for faculty to convert research grade software to commercially quality tools. The participants discussed ways to increase the adoption of the methods developed by the EDSE community among practitioners in the industry, and strategies to extended engagement to enable usage of research products.

1. *Choose the right problems from the application domains.*

The impact of the EDSE community can be maximized by appropriately selecting the problems that we tackle (as applied to other disciplines). The participants recommended that researchers should apply the computational design methods to problems that are of relevance to other communities (beyond EDSE). The industry impact can be increased through NSF-funded internships for grad students to work at a company and develop realistic test/benchmark problems. NSF internships can be used as a means for students to develop new applications, which would also encourage the students to engage in design through interesting applications and job opportunities.

2. *Collaboration within and outside EDSE*

The participants emphasized the need for interacting closely with researchers in design theory and methodology, and with researchers in other disciplines, such as computer science and social sciences. The community can learn from how researchers in other disciplines carry out computational design.

3. *Code Sharing*

The community should encourage the practice of sharing research code in open-source form. While there are several challenges in sharing the code (e.g., dilemma of having others quickly and rapidly replicate results vs. giving away the group's 'assets'), difficulty in releasing 'clean', well-commented codes, upwards compatibility challenge (i.e., Python modules change with time), several other communities have successfully adopted this practice. For example, in the area of uncertainty quantification, the practice of publishing all the code is the norm.

4. *Benchmark/Challenge Problems*

The community should work towards more benchmark/challenge problems (like those adopted by the multidisciplinary design and optimization community). NSF should consider funding the creation of databases of challenging problems ('marketplace of problems'). Funding should also be directed to meta-studies and replication of results.

5. *Publishing guidelines*

The community should consider developing publishing guidelines that facilitate replication of results. Journal papers should include sufficient information and tools for replication.

6. *Information sharing/dissemination*

Examples of applications that result from EDSE research can be advertised. Regular research updates on NSF projects can be disseminated through annual NSF EDSE report.

4.2 Design cognition

The primary challenges discussed in the breakout group on design cognition were (i) difficulty in replication of studies, (ii) barriers to collaboration, and (iii) difficulties in finding the right venues for publishing research outcomes. Replication is an issue that has been discussed in the past EDSE workshops also. Replication of studies is challenging because of the lack of incentives for replication of EDSE-related studies. It is difficult for researchers to get replication studies funded. It is equally challenging to publish results of replication studies. Additionally, there is stigma associated with failure of replication studies. The second challenge was related to the barriers in collaborating with social scientists. For example, social scientists, with their focus on isolating atomic phenomena, sometimes tend to oversimplify experiments which hinders representativeness of real engineering design scenarios. Collaboration is also challenging because of the difficulty in finding the right publication venue for collaborative publications. Different scientific communities have different publication venues, with different norms and expectations.

The participants discussed several ideas to address these challenges.

1. *Community support for conducting studies*

There is a need to consider how studies are being designed and provide the community with resources to do them well. The idea of pre-registering studies is gaining traction in several other social science communities. In top journals for the social sciences one needs to pre-register hypotheses and experimental design on the journal's website before conducting the study, and submitting the results to the journal. This is to avoid issues such as p-hacking. The idea is to hold the researcher to the hypothesis, and a first level of peer review can also be done at that stage.

2. *Shared data repositories*

In other disciplines, people put the details of their datasets and methods in a public repository so people can reuse the same datasets to do new studies. This is common in the machine learning community. The ML community has standard datasets and benchmark problems that the community uses. Within the design community, the Design Thinking Research Symposium (DTRS) also made videos and transcripts of protocol studies online. The participants recommended NSF to fund the development of similar datasets and benchmark problems.

The participants recommended an NSF workshop to discuss some of these issues. Perhaps NSF could work with NAS/NAE to do a workshop and write a report on some of these issues. This was done in the past ("Beyond Productivity") and has had a big impact. Such a workshop should include people in our community who do these studies, as well as social scientists. Such a group could peer review study designs to ensure that they are designed well before data collection begins.

3. *Training opportunities*

The participants highlighted the need to provide more research training opportunities for graduate students working on EDSE-related research. As an example, Clemson University offered an online class on research methods and students at Georgia Tech could take it for credit. Another example is the summer school for grad students organized by Clemson university and funded by NSF. The summer school was focused on learning how to do experiments with human subjects. The participants recommended continuation of similar initiatives, and finding ways to sustain them in the long run.

4.3 Systems Engineering

The breakout group on systems engineering discussed several challenges, some of them overlapping with the discussion in the computational design and design cognition groups. The key challenges included (i) diversity of methods and lack of comprehensive theoretical foundation for systems engineering, (ii) barriers to collaboration, (iii) navigating the research valley of death, (iv) challenges in building on each other's work, (v) gap between computational and human subject research, and (vi) challenges in decomposing grand challenges into smaller problems.

Due to the scope and scale of the problems and the diversity of application areas addressed by the systems engineering community, there is a significant diversity of methods used in the community. One possible reason for the diversity of approaches to systems engineering is a lack of comprehensive theory, which makes it more difficult to assess the impact of the proposed methods. Another major challenge in systems engineering research is the Research Valley of Death – the challenge of getting from fundamental research (funded by NSF) to something that can be used/funded by organizations such as DoD/NASA. In terms of technology readiness level (TRL), this can be viewed as increasing the level up from 4-6 to 7-9. There are challenges in moving beyond this range. One idea discussed during the breakout was to define a TRL for research and to apply this when communicating results. The research-readiness level can help level-set expectations from research.

The challenge associated with building on each other's work in systems engineering is due to (i) results being published in disparate areas and journals, (ii) culture of highly critical reviews/feedback on papers and proposals, (iii) incentive to work on things that are brand new, and (iv) lack of availability of data from publications. The participants discussed ideas for effectively engaging junior scholars on a well-studied area, e.g., inviting them to write short review/response, without enormous effort to understand underlying concepts and longstanding debate. Finally, there was discussion about challenges in decomposing grand challenges into smaller problems that the EDSE community can contribute to. Related issues include a lack of tangible metrics to assess performance (there is a mismatch between design targets and how the systems designed are used), difficulties in assessing the adoption of "successful" systems by the society, and the need to interface with public policy, ethics when defining success (it could potentially also slow down the progress). The participants provided several recommendations for addressing these challenges.

1. *Access to data*

Similar to the design cognition breakout group, the systems engineering group also suggested conducting a workshop (and lightning talks) focusing on datasets and data articles to help raise awareness and connect with metadata and sources. Conferences such as IDETC can host sessions focused on datasets.

2. *Benchmarks / standardizing experiments*

The use of standardized experiments (e.g., in psychology) and benchmarks can foster closer community collaboration. Frameworks for integrating different research methodologies (integrating experiments, case studies, observational studies, computational models, etc.) should be investigated. There is a need for benchmark models and framework for creating and maintaining models with open repository. This would facilitate verifying, validating, and comparing approaches. Hackathon competitions can be organized around standard problems.

3. *Funding*

NSF funding should incentivize writing review papers and papers about experiments that "fail". This should be seen as worthwhile activities.

4. Addressing diversity of research

Several ideas for addressing the diversity of research were discussed. These include characterizing research areas and writing review papers on them; special issues with diverse editor teams; NSF funding to support culture-change and review papers; directive from NSF on how to frame work that is fundamental but builds on existing research streams; slack channel or other ways to maintain conversations across workshops; and benchmark models and frameworks collectively built that enable comparison among approaches. The EDSE community should facilitate discussion via papers, i.e., papers in response to papers. Such an open discussion is currently lacking in formal writing within the EDSE community. There was also a discussion about the norms of reviewing articles within the community. Some of the participants felt that the reviewing norms are very critical. How can this culture be changed? There is a need for a more constructive feedback.

5. Interfacing with other disciplines

The participants recommended finding collaborators from other disciplines through combining conferences; small workshops that deliberately combine from different disciplines. There was also suggestion for interfacing with engineering education. Engineering researchers don't always have background to design educational approaches. Sometimes, techniques that are long debunked in education and/or very basic in those fields are used. There is potential for improving communication with experts in education.

6. Outreach

Several ideas for research outreach were discussed. Research with middle school students should lessen focus on calculations and focus more on abstraction/systems thinking. Students have idea that if something is difficult, it's not for them. Once the students are excited, effort to overcome difficult portions will follow. There is significant potential for impact by finding and working with rural/remote school districts, e.g., NASA program to build spaceflight hardware is concentrated in nearby areas. NSF and other funding agencies can incentivize working with more remote high schools.

The EDSE community should communicate value better to general audience/public. There were suggestions for new formats of dissemination such as general-audience lightning talks, interviews/talks by senior awardees to help communicate the "tribal knowledge" within the community. YouTube or other social media platforms can be used to explain to the outside community how EDSE is impacting society. There is a need to simplify and communicate value to congress.

There was discussion about the educational aspects related to systems engineering, specifically in grade school and undergraduate levels. The EDSE community can have a big impact by teaching some of the skills (e.g., abstraction) without going into entirety of systems engineering curriculum. The engineering design community made huge impact on how design taught in the US. There is potential to have similar impact in systems engineering. There is also a potential for broadening participation in EDSE research, specifically understanding why underrepresented groups are underrepresented in the EDSE community.

5. Appendices

5.1 Participants

2019 NSF EDSE Workshop and Grantees Meeting List of Attendees		
First Name	**Last Name**	**Organization**
Robin	Adams	Purdue University
Faez	Ahmed	University of Maryland - College Park
Dionysios	Aliprantis	Purdue University
Janet	Allen	University of Oklahoma
James	Allison	University of Illinois at Urbana-Champaign
Andres	Arrieta	Purdue University
Jesse	Austin-Breneman	University of Michigan
A. Emrah	Bayrak	Stevens Institute of Technology
Ilias	Bilionis	Purdue University
Ramin	Bostanabad	University of California, Irvine
Diann	Brei	University of Michigan
Alex	Burnap	Massachusetts Institute of Technology
Bradley	Camburn	Oregon State University
David	Cannon	NASA Langley Research Center
Ashish M	Chaudhari	Purdue University
Sikai	Chen	Center for Connected and Automated Transportation, Purdue University
Shikui	Chen	State University of New York at Stony Brook
Changqing	Cheng	Binghamton University
Adam	Dachowicz	Purdue University
Daniel	DeLaurentis	Purdue University
Abhi	Deshmukh	Purdue University
Andy	Dong	National Science Foundation
Xiaoping	Du	Indiana University - Purdue University Indianapolis
Vincent	Duffy	Purdue University
Bryony	DuPont	Oregon State University
Kim	Edwin	Purdue University
Paul	Egan	Texas Tech University
Tracy	El Khoury	Purdue University
Katherine	Fu	Georgia Institute of Technology
Mark	Fuge	University of Maryland - College Park
Kosa	Goucher-Lambert	University of California, Berkeley
Erica	Gralla	George Washington University

Paul	Grogan	Stevens Institute of Technology
Atharva	Hans	Purdue University
George	Hazelrigg	George Mason University
Sebastien	Helie	Purdue University
Daniel	Herber	Colorado State University
Babak	Heydari	Northeastern University
Koki	Ho	Georgia Institute of Technology
Zhen	Hu	University of Michigan, Dearborn
Kathryn	Jablokow	The Pennsylvania State University
Mohammad	Jahanshahi	Purdue University
Mark	Jakiela	Washington University in Saint Louis
Kai	James	University of Illinois at Urbana-Champaign
Roger	Jiao	Georgia Institute of Technology
Karthik	Kannan	Purdue University
Hanumanthrao	Kannan	Virginia Tech
Harrison	Kim	University of Illinois at Urbana Champaign
Sridhar	Kota	University of Michigan
Vinayak	Krishnamurthy	Texas A&M Univeristy
Benjamin	Kwasa	Missouri S&T
samuel	labi	Center for Connected and Automated Transportation, Purdue University
Matthew	Law	Cornell University
Astrid	Layton	Texas A&M University
Leifur	Leifsson	Iowa State University
Li Xin	Lim	Purdue University
Scott	Lucero	U.S. DoD Office of the Secretary of Defense
Yuzhen	Luo	Utah State University
Erin	MacDonald	Stanford
Richard	Malak	Texas A&M University
Christopher	McComb	The Pennsylvania State University
Anna	McGowan	NASA
Jessica	Menold	The Pennsylvania State University
Bryan	Mesmer	The University of Alabama in Huntsville
Mohammad	Miralinaghi	Center for Connected and Automated Transportation, Purdue University
Beshoy	Morkos	University of Georgia
Thanh	Nguyen	Purdue University
Julian	Norato	University of Connecticut
Philip	Odonkor	Stevens Institute of Technology
Bryan	O'Halloran	Naval Postgraduate School
Jitesh	Panchal	Purdue University
Ramana	Pidaparti	University of Georgia

Mark	Plecnik	University of Notre Dame
Karthik	Ramani	Purdue University
Thomas	Redick	Purdue University
Tahira	Reid	Purdue University
Yi	Ren	Arizona State University
Oscar	Rincon	Purdue University
Salar	Safarkhani	Purdue University
Zahra	Sajedinia	Purdue University
Alejandro	Salado	Virginia Tech
Hiroki	Sayama	Binghamton University
Daniel	Selva	Texas A&M University
Rob	Semmens	Naval Postgraduate School
Zhenghui	Sha	University of Arkansas
Jinjuan	She	Miami University
Murtuza	Shergadwala	Purdue University
Binyang	Song	The Pennsylvania State University
Nicolas	Soria Zurita	Pennsylvania State University
Robert	Stone	National Science Foundation
Joshua	Summers	Clemson University
Zoe	Szajnfarber	George Washington University
Andres	Tovar	Indiana University - Purdue University Indianapolis
Waterloo	Tsutsui	Purdue University
Cameron	Turner	Clemson University
Douglas	Van Bossuyt	Naval Postgraduate School
Jan	Vandenbrande	DARPA
Steve	Visser	Purdue University
Dr. Yan	Wang	Georgia Institute of Technology
Zequn	Wang	Michigan Tech
Wenzhuo	Wu	Purdue University
Hongyi	Xu	University of Connecticut
Denny	Yu	Purdue University
YUNBO	ZHANG	Rochester Institute of Technology
Xiaojia Shelly	Zhang	University of Illinois at Urbana Champaign
Feng	Zhou	University of Michigan, Dearborn

5.2 Workshop agenda

Sunday, October 6th, 2019	
6:00 – 8:00 pm	Welcome reception Holiday Inn City Center: 515 South St, Lafayette, IN 47901

Monday, October 7th, 2019 [Armstrong Hall: 701 W Stadium Ave, West Lafayette, IN 47907]	
7:30 – 8:30 am	Registration and breakfast
8:30 – 8:45am	Opening address; Overview of the goals and operation of the workshop
8:45 – 9:30am	"**Investing in US Innovation Ecosystem - The Case for a National Manufacturing Foundation**" by Dr. Sridhar Kota
9:30 – 10:15am	Emerging Frontiers in EDSE Research - Dr. Rich Malak - Dr. Shirley Dyke - Dr. James Allison
10:15 – 10:30am	Coffee break
10:30 – 11:45am	Parallel Breakout # 1: Needs/Challenges in diverse application domains. *How can EDSE research make sustained impact on diverse application domains, such as manufacturing, transportation, and smart and connected communities?*
11:45am – 12:15pm	Report out from Breakout 1
12:15 – 1:30pm	Lunch
1:30 – 2:30pm	"**Computational models for creative design: curiosity, novelty, and surprise**" by Dr. Mary Lou Maher
2:30 – 3:45pm	Parallel Breakout # 2: Opportunities created by emerging technology, changing workplace and society. *What are the new opportunities for EDSE research created by emerging technologies and the changing workplace and society?*
3:45 – 4:15pm	Report out from Breakout 2
4:15 – 4:30pm	Coffee Break
4:30 - 5:00pm	Dr. Rob Stone (Division Director, NSF CMMI)

	Dr. Andy Dong (Expert, NSF EDSE)
5:00 – 5:30pm	Lightning talks on recently funded EDSE projects
5:30 – 6:00pm	Break; Transition to Ross Ade Stadium (Shively Club)
6:00 – 8:00pm	**Reception** Location: Shively Club @ Ross Ade Stadium (Third Floor) 850 Steven Beering Drive, West Lafayette, IN

Tuesday, October 8th, 2019 [Armstrong Hall: 701 W Stadium Ave, West Lafayette, IN 47907]	
7:00 – 8:00 am	Breakfast
8:00 – 9:00am	"**Design Beyond Imagination**" by Dr. Jan Vandenbrande (DARPA)
9:00 – 10:00am	Lightning talks on recently funded EDSE projects
10:00 – 10:15am	Coffee Break
10:15 – 11:30am	Parallel Breakout # 3: Strategies for maximizing collective impact. *How can the EDSE research community maximize the societal impact of individual work by building on each other's work and leveraging from recent advances (scientific and methodological) in other scientific disciplines?*
11:30am – 12:00pm	Report out from Breakout 3
12:00 – 1:30pm	Way Forward, Closing and Lunch
[Optional]	
2:00 – 5:00pm	Roundtable on empirical research settings Location: Anniversary Drawing Room (Room 304), Purdue Memorial Union Address: 101 Grant St, West Lafayette, IN 47906

5.3 Breakouts

Breakout 1 (Monday, 10:30 am)			
Room	**Table**	**Theme**	**Discussion Lead**
1021	1	Design of Intelligent Autonomous Systems	James Allison
	2	Autonomy in Networked Systems	Mohammad Miralinaghi
	3	Personalized Health and Healthcare Systems	Paul Egan
	4	Autonomous Systems with Human Interactions	Hiroki Sayama
1103	5	Aerospace and Defense Systems	Douglas Van Bossuyt
	6	Aerospace and Defense Systems	Alejandro Salado
	7	Aerospace and Defense Systems	Bryan O'Halloran
	8	Design of Material Systems	James Kai
1109	9	Manufacturing	Zhenghui Sha
	10	Design of Smart Manufacturing Systems	Roger Jiao
	11	Consumer Products	Feng Zhou
	12	Consumer Products	Jinjuan She

Breakout 2 (Monday, 2:30 pm)			
Room	**Table**	**Theme**	**Discussion Lead**
1021	1	Technology: AI/ML	Yi Ren
	2	Technology: AI/ML	Chris McComb
	3	Technology: AI/ML	Mark Fuge
	4	Technology: AI/ML	Alex Burnap
1103	5	Workplace: Automation + Future of work	Kosa Goucher-Lambert
	6	Workplace: Automation + Future of work	Rich Malak
	7	Workplace: Automation + Future of work	Steve Visser
	8	Environment/Sustainability	Astrid Layton
1109	9	Technology: Additive Manufacturing	Andres Tovar
	10	Technology: Additive Manufacturing	Xiaojia Shelly Zhang
	11	Technology: Internet of things; Industrial Internet	Philip Odonkor
	12	Society: The networked society	Babak Heydari

Breakout 3 (Tuesday, 10:15am)			
Room	**Table**	**Theme**	**Discussion Lead**
1021	1	Computational Design	Cameron Turner
	2	Computational Design	Xiaoping Du
	3	Computational Design	Ramin Bostanabad
	4	Computational Design	Julian Norato
1103	5	Computational Design	Mark Plecnik
	6	Design Cognition	Sebastien Helie
	7	Design Cognition	Daniel Selva
	8	Design Cognition	Kathryn Jablokow
1109	9	Systems Engineering	Paul Grogan
	10	Systems Engineering	Emrah Bayrak
	11	Systems Engineering	Zoe Szajnfarber
	12	Systems Engineering	Erica Gralla