# Expanding evidence-based pedagogy with Design Heuristics

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## Abstract

Creative thinking during concept generation has been identified as a key source of successful innovations; thus, techniques to support creative conceptual design are imperative in engineering education. However, teaching students to “think innovatively” has been difficult because educators lack effective instructional methods. While there are a variety of proposed methods for idea generation, only one has been empirically validated in multiple scientific studies: Design Heuristics. Design Heuristics are prompts that guide designers in exploring the design space during concept generation. In empirical studies in engineering and design classrooms, Design Heuristics have been shown to be readily adopted by students, and to result in more creative, and more diverse, concepts.

The focus of this project is to create a set of Design Heuristics lessons for engineering students that can be incorporated directly into existing undergraduate courses at varied institutions. The project aims to refine these pedagogical methods through co-creation of lessons with engineering instructors from diverse institutions and backgrounds. Our goals include: 1) raise awareness of the importance of teaching students to generate creative concepts; 2) educate instructors on how to teach Design Heuristics within existing engineering classes; 3) assess learning outcomes of Design Heuristics lessons from diverse instructors, courses, and universities; and 4) develop an effective, easy-to-adopt pedagogy for educating students about how to generate creative ideas. In this paper, we present our vision for a sustainable foundation to develop of design pedagogy for transforming undergraduate education in engineering. We illustrate with some instructional lessons that have emerged from our work.


## Introduction

Generating ideas (ideation) is a crucial skill for all engineers. Engineers generate ideas to solve immediate problems and to support long-term solutions. With the increasing complexity of unsolved problems, successful engineering ideation is essential to our continued progress (even survival), as identified by the Grand Challenges in Engineering of the 21st Century [1-3]. Innovative outcomes are often traced to the concept generation phase of design, where multiple, creative ideas are developed, and diverse concepts evaluated and pursued [4, 5]. More, and more varied, concepts increase the potential for more innovative design outcomes. But despite its obvious importance, engineering education has instead focused on training students on the core technical methods needed in the later stages of the design process. Until now, the field has lacked evidence-based methods for *how* to successfully generate concepts, where Design Heuristics play a crucial role.

Prior research on concept generation in engineering has uncovered two types of cognitive difficulties: 1) an early attachment to initial ideas that lead to few alternatives [6]; and 2) the inability to break away from known products or example solutions [7]. Ullman et al. [6] found that designers did not explore multiple ideas, typically pursuing only a single proposed design. In a study by Ball and colleagues [8], engineers generated solutions with serious flaws, but still adhered to their original idea, working laboriously to make improvements to address its flaws. This cognitive difficulty has been termed "fixation," where the designer rarely chooses to spend time and effort in a search for a better alternative, and doggedly pursues an initial idea [7]. The second difficulty, fixation on an existing example, is exemplified in Jansson & Smith's [9] study, in which designers were shown an initial example of an unsatisfactory product and then made aware of its flaws. These designers produced solutions inferior to those who had not seen the initial example. In fact, the outcomes frequently included aspects and *flaws* from the provided example. Left to their own devices, designers are often stymied by existing ideas and their initial ideas, and as a result, stop short of generating novel concepts.

While not commonly integrated into engineering design courses, there are a variety of idea generation tools available to address the fixation problems in concept generation. A sample includes those aimed towards: 1) *the facilitation of idea flow*, e.g., brainstorming [10] and brainwriting [11]; 2) *the stimulation of initial idea formation*, e.g., analogical thinking [12], morphological analysis [13], and Synectics [14], and 3) *the transformation of ideas into more or better ideas*, e.g., lateral thinking [15], conceptual combination [16], SCAMPER [17], and TRIZ [18]. Other published tools include IDEO™ Method Cards [19], which focus on understanding a product's users, and "Whack Pack" cards [20], intended to help break out of habitual views by providing general techniques and decision-making advice.

These ideation methods vary in their focus, specificity, and usability. For example, TRIZ [18, 21] derived refinements of mechanisms and specific design tradeoffs that occur later in the design process based on engineering patents; however, its strategies are only useful once an implementation has been specified. For the concept generation phase, "brainstorming" recommends very general guidelines, including "suggest many ideas," and "do not evaluate ideas," [10], but provides little direction about *how* to generate ideas. Other methods provide general guidelines, e.g., SCAMPER [17], such as "combine" and "modify." Some methods also require extensive training and practice to become skilled in their use, e.g., Synectics [14] and TRIZ [18, 21].

Above all, none of these ideation tools have been empirically validated or empirically tested for their success in concept generation. Smith [22] conducted a systematic compilation of over 170 different concept generation techniques, and concluded, "Of the hundreds of existing methods, only brainstorming has been subjected to a substantial battery of performance tests. Moreover, these assessments have generally been inconclusive in their results" (p. 129). Consequently, engineering instructors have not had an evidence-based means for teaching how to perform concept generation. So far, only one method has been empirically derived and rigorously tested to determine that it leads to successful concept generation: *Design Heuristics* [23-25].

## Design Heuristics as a Method for Concept Generation

Design Heuristics are "cognitive prompts" that encourage exploration of a variety of solutions during ideation [26-28]. Based on the term "heuristic" in psychology, a cognitive heuristic is a simple "rule of thumb" used to stimulate a judgment or decision [29]. Cognitive heuristics are not guaranteed to lead to a determinate solution, as in the case of an algorithm; rather, they describe specific "best guesses" at potential solutions. Research in psychology shows that experts use cognitive heuristics constantly and effectively, and that their efficient use of domain-specific heuristics distinguishes them from novices [30]. They are intended to help designers move through a "space" of possible solutions, guiding designers to generate non-obvious ideas that are also different from one other. They are also intended to support designers in becoming "unstuck" when they have worked on a task for a long time and are struggling to generate more, and different, ideas. Design Heuristics include a specific set of 77 "rules of thumb" that have been shown to help designers and engineers generate possible solutions [23, 24, 31]. They can be applied repeatedly, and in combination, to produce a variety of novel and original concepts. They guide engineers in generating non-obvious ideas that are different from one other, providing a larger set of diverse ideas to choose from later in design [32].

For example, one Design Heuristic suggests making use of the "opposite surface" of an artifact. For example, shelves are designed to hold objects in place on their top surface; however, this heuristic suggests considering how the bottom surface might also play a role in the product's use. A shelf could provide hooks below for hanging objects (like coffee cups) or clips for hanging photos or reminders. By suggesting the use of the opposite surface, the heuristic helps the designer to consider alternative design concepts, but does not dictate a specific concept. By considering the heuristic, a designer would create new concepts that may not come to mind without it.

Design Heuristics were derived from three data sources [33]:
**1)** behavioral studies of student and expert conceptual designs [25-27, 32, 34];
**2)** analyses of award-winning concepts that transformed existing products [28];
**3)** a case study of a long-term project by a professional designer [32].

The research project began with a detailed investigation of approximately 400 varying and distinct, award-winning products. Their major elements and key features were identified for functionality, form, and user-interaction features. This process resulted in the identification of forty heuristics [28]. In a separate case study, 200 design concepts for a universal access bathroom generated by a single, very experienced professional designer were examined. Transitions between concepts and abstractions from the ways concepts were changed were uncovered [27, 32], resulting in over thirty new heuristics were identified. This long-term (2 year) project showed that specific heuristics reappeared repeated to create novel designs.

In a third set of studies, a think-aloud protocol technique was used to explore how both student and expert engineers generated and transformed concepts during a concept generation session [25, 26, 34]. We created an open-ended design task based on the Grand Challenges [1, 3, 35]. With minimal criteria to lead the participants, we asked them to "design a solar cooking device," and analyzed how each designer naturally created concept sets and transformed ideas. Their protocols were systematically coded for the presence of candidate heuristics, and we found evidence for the use of 60 heuristics in this dataset, many overlapping with those in prior studies.

Accumulating evidence from our three studies resulted in 77 unique Design Heuristics. To ensure their usefulness, each heuristic was observed multiple times, used by different engineers and designers, and observed in different design problems. The resulting empirically-derived Design Heuristics are listed in Figure 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Add levels | 20 | Change geometry | 39 | Incorporate environment | 58 | Scale up or down |
| 2 | Add motion | 21 | Change product lifetime | 40 | Incorporate user input | 59 | Separate functions |
| 3 | Add natural features | 22 | Change surface properties | 41 | Layer | 60 | Simplify |
| 4 | Add to existing product | 23 | Compartmentalize | 42 | Make components attachable/detachable | 61 | Slide |
| 5 | Adjust function through movement | 24 | Contextualize | 43 | Make multifunctional | 62 | Stack |
| 6 | Adjust functions for specific users | 25 | Convert 2-D material to 3-D object | 44 | Make product recyclable | 63 | Substitute way achieving function |
| 7 | Align components around center | 26 | Convert for second function | 45 | Merge surfaces | 64 | Synthesize functions |
| 8 | Allow user to assemble | 27 | Cover or wrap | 46 | Mimic natural mechanisms | 65 | Telescope |
| 9 | Allow user to customize | 28 | Create service | 47 | Mirror or array | 66 | Twist |
| 10 | Allow user to rearrange | 29 | Create system | 48 | Nest | 67 | Unify |
| 11 | Allow user to reorient | 30 | Divide continuous surface | 49 | Offer optional components | 68 | Use common base to hold components |
| 12 | Animate | 31 | Elevate or lower | 50 | Provide sensory feedback | 69 | Use continuous material |
| 13 | Apply existing mechanism in new way | 32 | Expand or collapse | 51 | Reconfigure | 70 | Use different energy source |
| 14 | Attach independent functional components | 33 | Expose interior | 52 | Redefine joints | 71 | Use human-generated power |
| 15 | Attach product to user | 34 | Extend surface | 53 | Reduce material | 72 | Use multiple components for one function |
| 16 | Bend | 35 | Flatten | 54 | Repeat | 73 | Use packaging as functional component |
| 17 | Build user community | 36 | Fold | 55 | Repurpose packaging | 74 | Use repurposed or recycled materials |
| 18 | Change direction of access | 37 | Hollow out | 56 | Roll | 75 | Utilize inner space |
| 19 | Change flexibility | 38 | Impose hierarchy on functions | 57 | Rotate | 76 | Utilize opposite surface |
| | | | | | | 77 | Visually distinguish functions |

Figure 1. Descriptive Titles for the 77 *Design Heuristics* [36]

Next, we developed a format for educating engineers on how to use Design Heuristics within a single classroom session, or over the period of an entire semester. For these studies, each heuristic was presented in the form of a 4 x 6 paper card. On the front of the card, a descriptive title and action prompt provides specific instructions on how to apply the heuristic, and an abstract image depicts the heuristic visually. On the back of the card, two product examples are shown, one from a variety of consumer products and a second from concepts for the same object (a chair). This example shows that each heuristic can be applied to a wide range of products and also to the same product category. A sample card is shown in Figure 2.

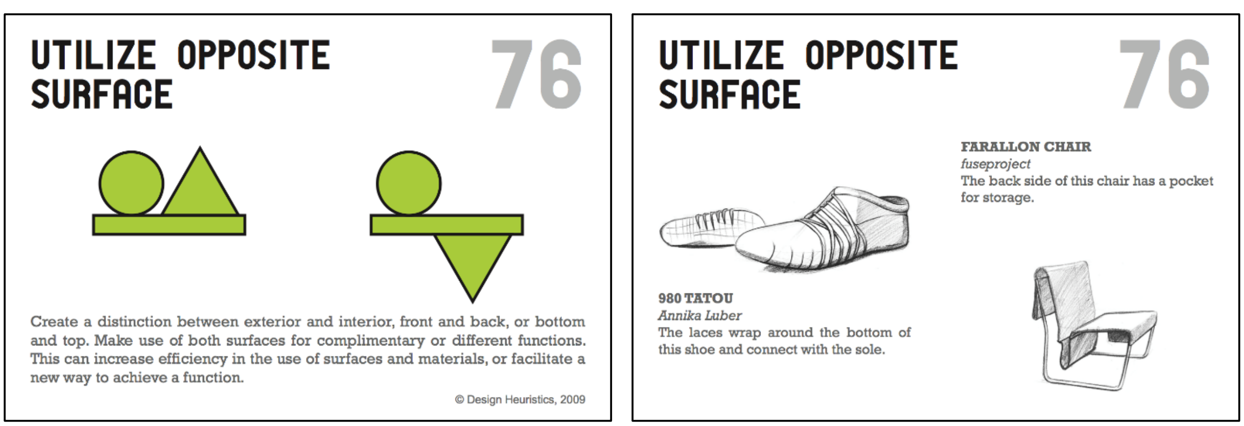


Figure 2. Heuristic Card Example: Utilize opposite surface

We tested these cards in classroom studies to assess the effectiveness of Design Heuristics in engineering classrooms [23, 24, 31, 36, 37] and in a test with professional engineers working on consumer products [38]. These studies showed that both engineering students and experts can learn to use the Design Heuristics cards within a short instructional session (10-15 minutes), and then go on to successfully create their own novel and diverse concepts. In one recent example, a team of students in a capstone engineering course applied Design Heuristics to a mechanical plate to balance a metal ball on its surface. The project's goal was to create the device to teach children how mechanical objects work. The *Adjust Functions for Specific Users* and *Rearrange* heuristics prompted the students to propose a concept that inverted the entire mechanism, bringing the motors and control elements up to the top, and putting the ball and plate down at a height more suitable for children to observe. The resulting product received a college award for the best design in the course. This example illustrates how the Design Heuristics approach can be incorporated into existing undergraduate engineering instruction and lead to exciting outcomes in student learning.

Building upon these findings, the next step in our research program is to develop a model for concept generation pedagogy that can be adopted by engineering instructors across the country. In this project, our central goal is to ensure the transferability and dissemination of our instructional materials and methods to a wide variety of engineering classrooms. Our project utilizes best practices in pedagogical development and foundational research on implementing new pedagogy in engineering.

**Project Plan**

Problem solving is generally regarded as the most important cognitive activity for engineers; Jonassen goes further to identify *design* as the most complex type of problem solving [39]. Our project expands the Design Heuristics approach into a series of instructional lessons for use within existing undergraduate engineering courses. These lessons will fill an important gap in instruction occurring in many engineering classes at the introductory, midrange, and capstone levels: training in the generation of new design ideas. Improving engineering students' design abilities is a requirement from ABET, specifically training in the ability to "design a system, component, or process that meets desired needs" (ABET [40], outcome *c*). Results obtained in these classroom contexts will provide essential groundwork how Design Heuristics can be effectively added to engineering pedagogy and impact ideation skills in engineering students.

The proposed pedagogy on Design Heuristics is unique within engineering education because it is founded on evidence. Past studies have demonstrated the effectiveness of the Design Heuristics method in concept generation [25, 32]. We have also conducted preliminary studies on the use of Design Heuristics in the engineering classroom, and demonstrated its effectiveness as pedagogy [23, 24]. This research base provides a solid foundation for our project because it is based on peer-reviewed, scientific studies. Many professions have advocated the use of evidence-based practice in their fields, including medicine, psychology, and education [41-44]. Our proposed project provides an application of "evidence-based practice" in engineering education to benefit students by providing state-of-the-art education in design.

**Project Context**

To implement this pedagogical outreach program, we:

1. *design and develop* workshops to train engineering educators from a diverse range of institutions on Design Heuristics pedagogy;
2. *collect* data about their students' learning outcomes in their courses at their home institutions;
3. *iterate* to improve the design of the pedagogy;
4. *train* engineering educators and assist them in holding workshops at their home institutions for other educators;
5. *support* this network of engineering educators by creating a virtual network for Design Heuristics instruction on an ongoing basis.

Our focus for this outreach effort is on educators teaching pre-engineering students, engineering students (both undergraduate and graduate), and engineering entrepreneurship. Furthermore, through our planned dissemination paths at national conferences, and our ongoing virtual network and instructional website, we will support the inclusion of sound design education in engineering classrooms in even greater numbers.

**Project Goals**

Our project is designed to support the implementation of lessons on concept generation skills within engineering education courses using our empirically demonstrated method: Design Heuristics. While many courses include concept generation, they often lack a specific method for teaching these skills. Our project fills this important educational gap. In this work, our goals are to:

1. raise *awareness* of the importance of educating student to generate creative concepts;
2. *train* instructors on how to teach Design Heuristics within existing engineering classes;
3. *assess* learning outcomes from Design Heuristics pedagogy from diverse instructors, courses and universities;
4. *incorporate* the lessons learned to develop an effective, easy-to-adopt pedagogy for educating students about how to generate creative ideas.

Key research questions include: How do instructors' emphases on concept generation change as a result of introduction to Design Heuristics at a workshop? How do instructors integrate Design Heuristics in their courses? What similarities and differences exist in Design Heuristics pedagogy across course level and type? How do students' understandings and approaches to concept generation change as a result of the pedagogy? What types of solutions do students produce when using Design Heuristics in different contexts with different problems?

**Developing Instructional Lessons for the Design Heuristics Pedagogy**

The primary aim of this project is to develop lessons supporting the application of Design Heuristics pedagogy in different contexts (course types, student levels, design problems). Within the last four years, we have taught Design Heuristics lessons to pre-engineering, undergraduate, and graduate students. We have observed where students struggle in their course projects, and what they need in order to apply the Design Heuristics lessons to their course assignments. We have collected data on students' design processes through semester–long projects as well as one-time lessons, and we have analyzed this data to understand what defines lesson effectiveness. In these classroom explorations, we have identified four contexts typically found in engineering courses where Design Heuristics can have a strong impact on student learning. These areas include 1) *Idea Initiation*, 2) *Idea Development*, 3) *Teamwork*, and 4) *Component Design* (Figure 3).

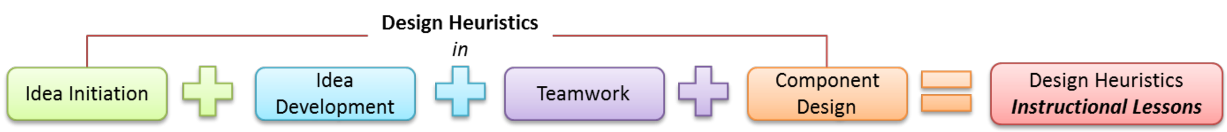


Figure 3. Instructional Lessons in the Design Heuristics Pedagogy

***Idea Initiation:*** Engineering students frequently struggle to generate solutions without basing their ideas on existing solutions [8, 45-47]. Finke and colleagues [16] characterized the formation of initial ideas as *generative*. For the idea initiation lesson, we created novel design tasks where students had sufficient technical knowledge. Students then practice creating new designs using different Design Heuristic cards. Our goal is to help students experience the flow of ideas made possible by the cognitive prompts of the heuristics. This concept generation lesson emphasizes the ability to continue generating new and different ideas, and allows students to see how possible it is to generate a *lot* of ideas for any design task.

***Idea Development:*** In a prior study, we found introductory engineering students often used Design Heuristics to *transform* a current concept into a new one [36]. In the idea development lesson, students are asked to generate their own initial ideas, and then apply Design Heuristics to add onto their existing ideas. In this lesson, Design Heuristics can be applied at differing points within the design process (after initial ideation, after idea selection, after prototyping, etc.) to allow students to practice with design iterations. Their progress along the way is traced back to the heuristics they used. In this way, the fixation arising from the presence of initial examples can be overridden by transforming them into novel concepts through the use of the Design Heuristics. The goal of this lesson is that even a single idea can be the source of many interesting novel ideas through transformations suggested by the Design Heuristics.

***Teamwork:*** Many engineering activities require teamwork, especially as the complexity of the design task increases. The team approach requires exploiting the knowledge and expertise of all members, while avoiding conflict resulting from their differences. Research has shown both positive [48] and negative [49] impacts on ideation outcomes from working in teams. In some cases, as a team develops more concepts, the quality of the concepts improves [50], and the team helps in selecting the best among multiple ideas. Preliminary results from a product design team of professionals suggests group brainstorming using Design Heuristics can help to focus innovations through group discussion [38]. Following this model, one version of the team lesson has the group examine a single heuristic as a prompt to discuss multiple design variations. They then proceed to a new Design Heuristic, using it as a means of focusing group discussion on specific innovations. In a second version of this lesson, each team member works with Design Heuristics separately, and then the groups joins together as a team to review initial concepts. In an third version based on the “brain writing” technique [51], students within a team individually generate concepts using one Design Heuristic card, and then pass their concepts to the next team member, who attempts to improve on the concept using a new Design Heuristic card. In a fourth version of this lesson, each student works on the same concept individually while the team members are passing the heuristics cards to each other, and applying new heuristics to a single ongoing concept. This step of “building on” others’ ideas is cited as an important advantage of group work in design firms such as IDEO [48].

***Component Design:*** This lesson builds on a curricular goal in most engineering courses: designing products using incremental changes to improve components. In industry, this allows companies to continue production while bringing improved, new-generation products to the market. However, when engineering students are trained to analyze components, they are not given instructions on how and when to separate designs into components, and to tackle design issues independently. The Component Design lesson is framed around the differences in designing an entire product versus making modifications to its components. In this lesson, students decompose existing products using functional decomposition (or start with the design problem and decompose the functions using morphological analysis [13, 51]), then redesign individual components using Design Heuristics, and finally suggest new versions of the product based on combinations of the redesigned components. In a second version, students are asked to decompose a function into sub-categories, and generate full concepts for each type of function. This lesson teaches students to generate ideas through decomposition and recombination.

These four lessons provide a sequence of pedagogy to support deeper learning by students, [52] and provides flexibility for instructors to choose the lessons that fit best within their class contexts.

## Implications and Future Work

*1. Developing Workshops and Disseminating the Instructional Lessons:* Through “Train the Instructor” workshops, we aim to reach instructors attending the engineering education conferences. The aim of the workshop is to provide a diverse set of participants with a deep understanding of our research, and the lessons and assessments we have developed to support ideation. The workshop supports instructors in developing specific plans for their own courses so they can return to their institutions prepared to integrate Design Heuristics pedagogy into their teaching. Further, we will invite these instructors to partner with us (or work independently) to prepare case studies about their experiences to share with the larger community through conference presentations, future workshops, and in our virtual network.

During these workshops, we will share the Design Heuristics lessons and assessment techniques. We will also help participants to develop their own implementation and data collection plan. The instructor workshop will be interactive and include Design Heuristics instructional materials as well as 15 Design Heuristics card sets for use by their students.

*2. Improving the Design Heuristics Pedagogy:* We will analyze and synthesize the findings from the first round of instructors attending the workshop. One of our key principles is to *continuously iterate based on feedback and assessment* to improve the Design Heuristics pedagogy. Consequently, we view this stage of learning from the first round of classroom instructors as key to developing the strongest possible pedagogy.

To guide revisions of our instructional lessons, we will begin employing a co-creation approach [53, 54]. We will work with engineering educators who participated in our workshop to adapt the lessons based on their experiences in the classroom. We will discuss proposed lesson and course integration structures, seek feedback, and ask participants for their views on the perceived value and challenges in working with the Design Heuristics lessons. We will also encourage writing collaborative papers with implementers, sharing their experiences and the analysis of student outcomes. We will also use the collection of student learning outcomes to determine how to improve the effectiveness of the instruction. Based on our findings, we will begin the creation of an online database for Design Heuristics instructional materials, called The Design Heuristics Hub (DHH). This will include revised instructional materials, assessment materials, and evidence from classroom implementations.

*3. Consolidating Materials and Findings in an Online Instructional Network:* We will collect and analyze data from our trainers' experiences, attend local workshops when the trainer requests help, and continue developing our Design Heuristics online hub to allow new instructors to join the network. The online network will serve instructors from our first workshop and instructors taught at locally-led sessions. This will ensure a core group of users for the virtual network and provide an active community for new instructors to join. Final versions of our Design Heuristics lessons will be available through the Design Heuristics Hub, along with video examples of each from actual implementations. The Hub will provide a venue for gathering evaluations and suggestions based on lessons learned through ongoing implementation by instructors. The user network supported by the website will allow us to continue to improve and expand the instructional materials, and it will also increase interaction and cooperation among engineering educators. Educators, who apply Design Heuristics in their classes using the instructional lessons provided, will also be asked to upload data they collected to share with us and others and to contribute to the assessment of learning outcomes. For the future sustainability of this project, we plan to offer regular webinars for new instructors and to continue to offer one-day workshops at engineering education conferences annually.

**Discussion**

Our results demonstrated that Design Heuristics can facilitate exploration beyond the 'obvious' solutions, and that the concepts guided by Design Heuristic cards are more creative and diverse. These empirical studies are listed in a prior paper [33], along with the research questions, data collected, and the results. The Design Heuristics approach contributes an evidence-based method to idea generation in engineering.

This project follows the success of our initial efforts to implement this evidence-based pedagogy within engineering courses taught by educators at diverse universities. The project investigates how to best implement this new pedagogy in actual classes, and then how to scale up the implementation by training educators across institutions to bring this new curriculum into their existing engineering courses. The result from this project is an evidence-based instructional intervention tested in many classrooms and by many instructors outside of the research team.

Data from their experiences will be incorporated back into the pedagogy and the resulting resources improved upon and provided in an ongoing virtual Design Heuristics Hub to support future educators. The evidence collected at each stage of this work will improve the Design Heuristics pedagogy, and broaden its impact in engineering classrooms across the country.

Most importantly, this project fills a gap in engineering education in the United States today: Where do new ideas come from? The Design Heuristics pedagogy successfully trains engineers to generate novel ideas, transform existing ideas in new directions, create multiple concepts to choose from, and to increase the diversity and creativity of the concepts considered. Further, the skills acquired by students using this pedagogy are developed through concrete, reproducible methods based on scientific studies demonstrating their effectiveness. While most engineers recognize the need for innovation in concept generation, they spend little, if any, time offering actual instruction to students on how to accomplish it. The Design Heuristics approach revolutionizes engineering education by demystifying the creation of concepts. After learning to use Design Heuristics, this instruction can be applied to every design project encountered, and the heuristics themselves can become natural ways for students to think about variations in designs.

In addition to its direct effects, this project also serves as a blueprint for other efforts to propagate change in STEM education across diverse institutions. The carefully constructed iterative process within the project ensures that what can be learned during each phase is brought back into the development of the pedagogy, ensuring that the final instructional program fully benefits from the experiences of many instructors during implementation. In addition, the project offers a novel training method in STEM education of first teaching educators to use the pedagogy in their own classes, and then expanding their participation to take responsibility for educating teaching staff at their own institutions. This builds a natural network of individuals and groups who are using the pedagogy successfully and provides an ongoing online resource for new educators to join. The project is driven by the principles of effective professional development to ensure the most impactful program possible. As a result, the lessons learned will inform us about how to accomplish change in STEM pedagogy across instructors, courses, and institutions across the United States.

Finally, this project has the potential to influence how people think about the STEM fields. While demand for practitioners in these areas continues to grow, student interest wanes, and is especially low in underrepresented groups such as women and minorities. STEM fields may be perceived as complex, computational approaches with a single correct answer. In reality, science and engineering call for *divergent* thinking and for the generation of new questions and solutions that cannot always be solved by equations. This project directly addresses this point by emphasizing the role of creativity in engineering design. It provides a method to help students generate novel, original concepts, and to become skilled and confident about doing so. It emphasizes how engineering allows one to leave their unique mark on their work, to contribute in a way that no one else has previously offered. This desire to feel a personal engagement in the scientific process may matter even more to students who see themselves as different from a "typical engineer." This project informs students that their ideas must be creative and informs instructors about how to train their skills to meet this challenge within STEM education.

## Acknowledgements

This research is funded by the National Science Foundation, Division of Undergraduate Education, Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES Type II) Grants # 1323251 and #1322552.


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