

Design Practitioners' Perspectives on Methods for Ideation and Prototyping

ALICE M. AGOGINO

Department of Mechanical Engineering, University of California, Berkeley, Berkeley, CA 94720, USA. E-mail: agogino@berkeley.edu

SARA L. BECKMAN

Haas School of Business, University of California, Berkeley, Berkeley, CA 94720, USA.

Department of Mechanical Engineering, University of California, Berkeley, Berkeley, CA 94720, USA.

E-mail: beckman@berkeley.edu

CARMEN CASTAÑOS

Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

E-mail: ccastano@mit.edu

JULIA KRAMER

Department of Mechanical Engineering, University of California, Berkeley, Berkeley, CA 94720, USA.

E-mail: j.kramer@berkeley.edu

CELESTE ROSCHUNI

Department of Mechanical Engineering, University of Maryland, College Park, College Park, MD 20742, USA.

E-mail: drc@umd.edu

MARIA YANG

Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

E-mail: mcyang@mit.edu

TheDesignExchange is a site dedicated to the support and development of the design thinking community. Its mission is to provide an online space for design thinking practitioners to share, discuss, and explore design thinking, allowing both novices and practitioners to expand and hone their expertise. Though there are many introductory experiences and courses available in design thinking, it is often difficult to find resources and support for advancing to the next stage of professional development, an aspect of which is being able to intelligently choose among the myriad methods available, rather than relying on the subset of methods learned in school. *TheDesignExchange* aims to fill that void by organizing the available design thinking methods, developing a community of design educators and practitioners to evaluate those methods, and helping educate the next generation of design innovators. This paper focuses on insights gained from two practitioner workshops associated with ideation and prototyping methods and describes the results of pilot testing with product design students in an upper division multidisciplinary course at UC Berkeley.

Keywords: design thinking, design methods, ideation, prototyping

1. Introduction

Many reports emphasize the increasingly multidisciplinary nature of engineers' work, and the need for universities to train young engineers to work effectively with other disciplines. Design thinking is an inherently multidisciplinary process used by engineers, designers, architects, business people, and educators [1–4], but these disciplines have each developed different approaches based on their own mindsets, skillsets and toolsets. Human-centered design methods, applied in the early stages of the product or solution development process, include developing insights through deep empathy for customers, the integration of divergent and convergent thinking, and rapid iteration around alternative concepts and prototypes [2, 3, 5, 6]. Finding the right design tool or method for any

particular problem can be challenging, especially when presented with options from multiple disciplines. *TheDesignExchange* provides a structured and cross-disciplinary ontology that highlights successful design methods in use today, their variations, and examples of their use [7–12]. It thus provides educators and practitioners alike with a versatile library of proven tools applicable to a range of disciplines. By promoting a community-of-practice model focused on an interest in the application of design processes/methods, *theDesignExchange* supports the cross-pollination of methodologies among the diverse range of contributors engaged in design.

To support educators and practitioners in exploring and expanding their design thinking expertise, *theDesignExchange* has collected a library of over 300 human-centered design methods from the many

disciplines in the design thinking space, including methods commonly used by engineers, designers, architects, business people and educators. To organize these methods and facilitate talking about methods and design thinking practice in general, we developed an ontology of design methods [13]. Drawing on previous work done in design theory, communities of practice, and expert/lead user-generated content, we determined that input from the design thinking community of practice should be included in both the ontology and site development. This input was gathered to (1) evolve the ontology structure and terms, (2) frame the features for *theDesignExchange* portal, and (3) build a sense of ownership over the portal within the community of practice to help encourage its adoption as a community resource. This paper focuses on the insights gained through two of a series of five workshops held with design practitioners to gather this input: one workshop focused on *Ideate* methods and one workshop focused on *Build* (i.e., prototyping) methods. To demonstrate use of *theDesignExchange* on advanced undergraduate product design students, pilot exercises conducted in an upper division multidisciplinary course at UC Berkeley are summarized.

2. Background

The methods in *theDesignExchange* were collected through a literature review, drawing on academic publications (e.g., [14, 15]), online collections (e.g., [16, 17]), books (e.g., [4, 10]), and industry toolkits (e.g., [18, 19]). Identical methods between sources were combined, noting the multiple names used for the method. Similar, but not identical, methods were grouped as *variations*—for example, a *mobile diary study* is listed as a variation of a *diary study*.

Four initial workshops were then conducted in 2011 and 2012 focusing on understanding the needs of the community, which helped to direct the development of a prototype of *theDesignExchange*. In this prototype, by matching method definitions with method group descriptions, the methods were organized into five preliminary groups associated with the design process, which are now called: *Research*, *Analyze*, *Ideate*, *Build*, and *Communicate* (originally called *Information Gathering*, *Information Processing*, *Ideation*, *Building and Communication*). Within each of those groups, methods were further categorized based partially on previous work collected during the literature review, and partially on differentiating characteristics between methods. In this paper we focus on those workshops associated with ideation (called “ideate” methods in *theDesignExchange*) and prototyping (called “build” methods in *theDesignExchange*). *Ideate* methods focus on creating new ideas for products, services, experi-

ences or business models. In addition to brainstorming and brainwriting methods, methods and categorizations schemes include those from gametorming [20] and co-design.

Build methods allow designers to move from concepts to physical or visual realization. The categories of this group pull from a number of sources and build off of work described by Hartmann [21], who reviewed prototyping methods in particular. The scope of *Build* methods includes horizontal slices, vertical slices, and the full scope. A horizontal slice explores a breadth of functionality, such as with a customer journey map. A vertical slice explores one functional aspect of the design in depth, such as a mechanism mock-up [7]. A more thorough discussion of the overall method ontology can be found in [13]. Roschuni, et al., [22] highlight insights from the workshops on *Research*, *Analyze*, and *Communicate* methods.

3. Methodology

3.1 *theDesignExchange* in design practice

In order to evaluate the authenticity of its methods and the approaches used in tackling design problems in industry, *theDesignExchange* hosted a series of workshops with design practitioners from the San Francisco Bay Area in California, between July and November 2014. Workshops ranged in size from 20–35 participants, with disciplines ranging from marketing to UX design to engineering design.

In this paper, we focus on two of these workshops: one on *Ideate* and the other on *Build* methods. Workshop participants were recruited through a mailing list of over 500 professional design and user researchers in the local geographic area. Approximately half of this pool identified as human-centered design researchers or user experience (UX) designers. The rest identified as industrial designers, product designers, design strategists, or design educators. Those interested in the workshops then signed up to attend through eventbrite.com, and there was no formal “selection” of attendees. Workshops were hosted at a variety of design and user research firms in San Francisco, but followed a common format: (1) networking and refreshments, (2) short presentation, (3) hands-on activities, and (4) sharing and discussion. The hands-on portion of each workshop was chosen to engage participants in a meaningful design activity that could then be used to inform *theDesignExchange*. Though *theDesignExchange* team developed these activities, a member of the host company worked with the team to conduct each workshop. Members of *theDesignExchange* team took notes and photographs to document the workshop activities and outputs during both the small group discussions and the

large group share-outs. All of the documents, drawings, and clusters created were collected for later analysis. A description of the activities for the *Ideate* and *Build* workshops is given below in Sections 4 and 5, respectively.

3.2 *theDesignExchange* supplementing the classroom

The educational benefits of *theDesignExchange* were further examined in an educational context with advanced product design students in an upper division, multidisciplinary course taught at UC Berkeley in Spring 2015 with 82 students (28 female, 54 male) from various fields of engineering, as well as computer science, architecture, business, humanities and social sciences. Many of these students had taken prior introductory design courses in their own major or through the student-led design thinking course run by students in the Berkeley Innovation club [23]. The course studied the design process and conceptual design of products, services, experiences, software, and business models. In this project-based learning course, a student's design ability is developed in a design project or feasibility study chosen to emphasize innovation and ingenuity, and to provide wide coverage of engineering and business topics, with an emphasis, this semester, on entrepreneurship opportunities. Social, environmental, economic, and political implications are included as considerations in the design project. There is also an emphasis on hands-on creative components, teamwork, and effective communication. Near the start of the semester, students were asked to complete an online creativity test to measure their self-assessments of creative confidence and attributes [24, 25]. During the second half of the semester, the students were given the test again, with the order of the questions rearranged. The creativity assessment presented statements on problem solving and ways of working and asked students to assess themselves as “not at all”, “rarely”, “sometimes”, “often” and “very often” for each statement. For each question, a student could get between 1 and 5 points based on their assessment, with a higher score indicating a higher level of creativity for that statement, giving a total possible score of 80 across 16 statements.

During the Spring 2015 semester, several ideation methods (brainstorming, attribute listing [i.e., morphological matrix], metaphorical/analogical reasoning) featured on *theDesignExchange* were presented to students during class. As a part of the course, students were asked to complete a concept generation exercise, including a description of their concept, a sketch, and a list of features and attributes. They were also asked to list specific creativity methods, if any, that they used during the exercise.

Each student was tasked with generating 10 concepts individually before expanding them with team exercises. Students were encouraged to browse the “ideate” section of *theDesignExchange* to find ideation methods to use for this exercise. The students were asked to use a concept half-sheet form to capture the output of their concept generation work. The goal was to see which methods were most frequently chosen by students and whether there were methods used by students not in *theDesignExchange*.

Students were also given the option of completing an online *Ideation and Early Prototyping Module* to help them become familiar with a range of design methods and with *theDesignExchange* as a tool for finding new methods. The module asked students to learn about three specific ideation methods listed on *theDesignExchange*: Attribute Listing; Do, Redo, Undo; and Forced Analogy, as well as three methods for prototyping: Paper Prototyping; Activity Modeling; and Experience Prototyping. These methods were selected because they spanned a spectrum of strategies. Students were asked to explore the range of other ideation methods at *theDesignExchange* and explain which they found most interesting and why. They were then asked to respond to five open-ended questions that involved applying the methods to simple design examples. An accompanying rubric was developed to assess the quality of responses to the module. If a student's response was assessed as satisfactory, the student would become eligible to receive a badge (the Ideation and Early Prototyping badge) from *theDesignExchange* to indicate that they had some level of familiarity with a range of ideation methods. Pilot testing suggested that the module would take about an hour to complete. As an incentive to complete the module, students were told that one submission would be chosen at random and be awarded \$100.

4. Ideate workshop

During the *Ideation Workshop*, held at DesignMap on 23 October 2014, participants were given an introduction to *theDesignExchange*, and then asked to spend 30 minutes in groups of 4–6 designing the user experience for the search function of the site. The design task is shown in Fig. 1. They were provided with a list of roughly 40 ideation methods that can be found on *theDesignExchange* to use as they addressed the design task.

We used a design approach developed by our collaborators at DesignMap called a “design swarm” in which a group of 10–15 designers or other skilled brainstormers get together to focus on a new, challenging problem. The group of designers is split into groups of 3–4 to generate ideas together

Design Task

- Come up with a solution to make finding methods on *theDesignExchange* easy and intuitive. Consider novel UIs (we can always scale back later).

Design Principles

- Make it easy for novices and experts (you!) to find the methods they're looking for, even if they don't know exactly what they are looking for.
- Let users pause and come back: when a user leaves the site and comes back, they should be able to easily pick it up where they left off.
- Allow users to build a reputation or expertise and network with each other.
- Empower users to create a community and a shared body of work.
- Allow users to efficiently manage their time spent on design activities.
- Create a fun and energetic environment that users enjoy participating in.

Fig. 1. Design task given to participants during ideation workshop.

for one hour. After an hour they reconvene to present their ideas as photos of their whiteboards. DesignMap recommends this as an effective method for jumpstarting a project [26].

To address the design task, the five groups were each given the freedom to pick their preferred ideation method, employing methods from a reference sheet of methods in *theDesignExchange* (Fig. 2), if desired.

- Group A began with a “post-it session” to get biases and ideas from each member, and then

worked collaboratively to develop a single concept to present during the “share-out.”

- Group B used a method called “6 Up Sketches” where each group member generated a rough sketch for six unique concepts, leading to six sketches per group member.
- Group C started by thinking out loud to define and elaborate on three general ideas.
- Group D used a method called “Reverse Brainstorming,” or “The Anti-Problem” which asks participants to generate solutions for the opposite of the problem they are working on (i.e.,

DESIGNEXCHANGE

Ideation Methods BY PURPOSE

MINDSET PREPARATION · DIVERGING · BUILDING ON IDEAS · CONVERGING · FULL CYCLE

Other Categorization Schemes:

By Scope: FEATURE · PRODUCT/SERVICE · SYSTEM

By Group Size: INDIVIDUAL · SMALL GROUP · LARGE GROUP · CROWD

By Audience: SELF · CORE TEAM · OTHER STAKEHOLDERS · USERS

By Activity Type: CREATIVE WRITING · CONVERSATION · BRAINSTORM · GAME

PREPARATION



When **bodystorming**, you imagine what it would be like if the product existed, and act as though it exists, ideally in the place it would be used. Its going through an idea with improvised artifacts and physical activities to envision a solution. By enacting the experience, the participants will naturally explore new possibilities.



Role playing helps designers imagine new design approaches and communicate design intentions. Role playing should create a safe environment for people to practice performing different roles in order to better understand other points of view.



The **show and tell** technique uses objects or props to help designers explore/discuss the topic at hand. Each participant brings an item they feel represents the topic and is asked to explain why they chose the object. Upon listening to each participant's understanding of the topic, the entire group has a better knowledge of the topic and its implications.



In **reverse brainstorming**, the team breaks into small groups and comes up with solutions to the opposite of the problem they're working on, e.g. how to prevent customers from buying-in. The goal is to help teams evaluate a problem differently, break out of existing patterns, and get people thinking again, so the more extreme the anti-problem, the better.

Fig. 2. Image from the sheet given to participants during Ideate workshop.

how to prevent site users from discovering new methods). This group uniquely chose this method at random from the reference sheet of methods.

- Group E worked collaboratively from the start to define and articulate the details of one idea.

The workshop highlighted a few of the many ways practitioners approach idea generation. One participant remarked that they often choose methods based on what “sounds fun” or interesting at the moment. Some groups took time to choose a formal method while others jumped right in without a formal plan for ideation. Even expert designers commented that *theDesignExchange* exercise exposed them to new methods that they would add to their toolbox. Based on feedback during

the discussion phase of the workshop, we revised the initial categorization scheme for classifying *Ideate* methods. This scheme is shown in Table 1. Note that these “categorizations” are not mutually exclusive. A method may be “tagged” with more than one category per theme.

5. Build workshop

During the *Build* Workshop, held at Autodesk’s new prototyping facility, Pier 9 on 24 July 2014, the participants were first given a short presentation on methods of prototyping and building. They were then split into groups of 4–6 and each given a set of roughly 35 prototyping method cards from *theDesignExchange*, complete with a method title and a brief description (Fig. 3).

Table 1. Revised Categorization Scheme for Ideate Methods

Theme	Category	Description
Activity type	Talking	These methods stimulate conversations among group members, and are therefore methods for indirect ideation.
	Drawing	These methods use drawing to result in creation of ideas.
	Deciding	These methods help to down-select and choose ideas.
	Writing	These methods use creative writing techniques to indirectly develop ideas.
	Building	These methods use building (prototyping) to result in creation of ideas.
Purpose	Prepare mindset	These icebreaker type of methods prepare participants for ideation.
	Diverge	These methods allow participants to freely diverge and generate new ideas.
	Build on ideas	These methods allow participants to build and elaborate on previously created ideas.
	Converge	These methods allow participants to assess (i.e., for desirability, viability, feasibility) and prioritize ideas.
	Full cycle	These methods can be used during the full design process cycle.
Desired scope of impact	System level	These methods are most useful for coming up with new business models, product-ecosystems, etc.
	Product level	These methods are most useful for coming up with new products or services.
	Feature level	These methods are most useful for coming up with new features of a particular product or service.
Participants	Individual	These methods allow a solo participant to ideate.
	Core team	These methods allow a core team of designers and design researchers to ideate together.
	Relevant stakeholders	These methods allow members of the company or organization (but outside of the design or research team) to ideate.
	Users (co-design)	These methods allow members of potential customer and/or user groups to ideate.
Group size	Individual	These methods are meant for an individual participant.
	Small	These methods are meant for a group of 2 to 8 participants.
	Medium	These methods are meant for a group of 8 to 25 participants.
	Large	These methods are meant for a group of 25 to 50 participants.
	The crowd	These methods are meant for a group of more than 50 participants.
Complexity	Simple	These methods require 2–3 steps.
	Average	These methods require 4–8 steps.
	Complex	These methods require more than 9 steps.
Time	Quick meeting	These methods are suitable for a meeting of 30 minutes or less.
	Normal meeting	These methods are suitable for a meeting of 1 to 2 hours.
	Half day	These methods are suitable for a meeting of about 4 hours.
	Full day	These methods are suitable for a meeting of about 8 hours.
	Multi-day	These methods are suitable for several sessions taking place over multiple days.
	On-going	These methods require continuous collection and are often less structured.

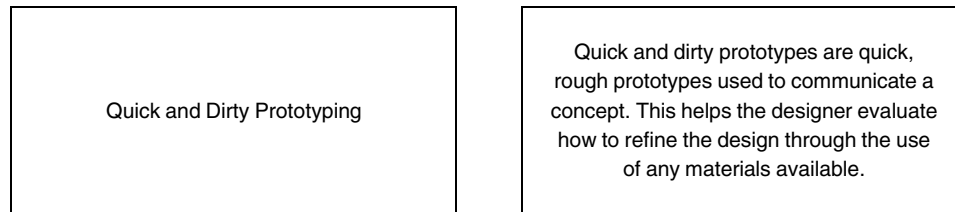


Fig. 3. Example of a method card (front and back) given to participants during Build workshop.



Fig. 4. Participants card sorting during Build workshop.

They were then asked to conduct an open card sort, taking the method cards and sorting them into categories of their choosing (Fig. 4). This activity led to a wide range of categorizations and highlighted the many different ways that practitioners think about building methods across disciplines.

In the discussion that followed, participants in the *Build Workshop* highlighted usability issues with the methods and their descriptors. For example, participants stated that the methods were harder to recognize by name than by description. This led to a conversation on the utility of “aka”s and related methods, to make them more easily recognizable by designers with different backgrounds. Participants also suggested providing representative pictures of each method along with examples of the method in use on *theDesignExchange*.

To present the methods in *theDesignExchange*, workshop participants suggested arranging methods in the order in which they would be used in a design process. They also proposed the use of spectrums on which to orient the methods (e.g., virtual to physical), but noted limitations with this approach.

Participants posed questions to help categorize methods: for what kind of audience is the designer building? What resources are available? What is the skillset of the designer? These questions all pose areas for further research and are noted as very important for a designer or design researcher to choose an appropriate building method.

Finally, participants spoke of a recommendation system interface that would be helpful in choosing and discovering methods. They brought up Spotify and Netflix as examples of systems that offer similar

methods; a similar interface would be useful in *theDesignExchange*.

Following the workshop, we modified our categorization scheme for classifying *Build* methods. This scheme is shown in Table 2. As with Table 1 for *Ideate*, the *Build* “categorizations” are not mutually exclusive. A method may be “tagged” with more than one category per theme.

6. Pilot testing on advanced design students

6.1 Half-sheet concept generation results

The half-sheet concept generation exercise was initiated as an individual homework assignment, which was then used to expand concepts during an in-class team exercise. After browsing the “ideate” section of *theDesignExchange* to find ideation methods to use, students were asked to list specific creativity methods, if any, that they used during the exercise. An example individual contribution is shown below in Fig. 5.

Out of the 36 methods collectively listed by students in the concept generation exercise, 11 methods were featured in *theDesignExchange*. A summary of the methods used that are from *theDesignExchange* is in Fig. 6.

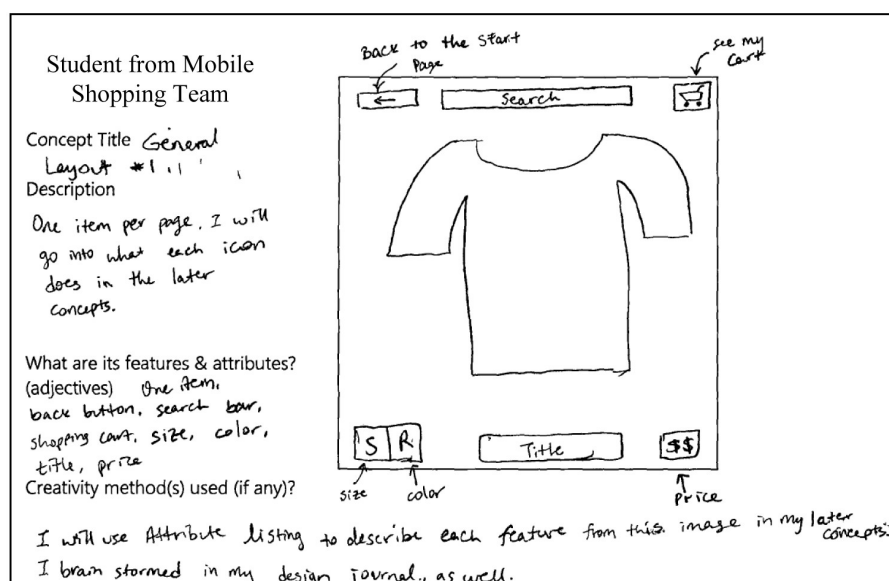
In addition to the 11 methods from *theDesignExchange*, students listed nine methods that were related, but used alternate names, to methods featured in *theDesignExchange*, suggesting that synonyms should be included to assist browse and search features. Two methods related to TRIZ (e.g., “evolution”) were not included, but will be added in future. Fourteen methods listed were either too generic (e.g., “divergent thinking”, “concept generation”, “problem solving”) or unknown to the authors. The authors are following up with the students for those in the latter category. Fig. 7 shows the frequency with which students mentioned methods that were not listed on *theDesignExchange*. Only methods mentioned three times or more are included.

6.2 Creative confidence

Midway through the semester, after *theDesignExchange* completed in-class activities of early proto-

Table 2. Categorization Scheme for Build Methods

Theme	Category	Description
Stage of process	Mock-up	These methods produce prototypes that are not fully functional.
	Operational	These methods produce a prototype that has the look and functionality of the final design.
	Production	These methods produce a prototype that is ready to be produced.
Fidelity	High	These methods produce a realistic prototype with the look and function of the final design.
	Medium	These methods produce a semi-complete prototype of the final design.
	Low	These methods produce a prototype that is easy to create, inexpensive to change, and good for providing a basic mockup.
Offering format	Digital offering	These methods produce a digital prototype.
	Physical offering	These methods produce a physical prototype.
	Either	These methods can be used to produce a digital or physical prototype.
Product or service	Product	These methods are useful to prototype a product.
	Service	These methods are useful to prototype a service.
	Either	These methods are useful to prototype either a product or service.
Format	Abstract	These methods produce a prototype that enhances the designer's understanding of what it might be like to use the product or service.
	Virtual	These methods produce a prototype using a digital medium.
	Tangible	These methods produce a prototype using a tangible medium.
Aspect	Role/context	These methods produce a prototype that explores the product's role in the larger use context.
	Appearance	These methods produce a prototype that explores the product's visual appearance.
	Implementation	These methods produce a prototype that explores the technical implementation of the product's function.
	Behavior	These methods produce a prototype that explores a product's behavior and response.
Scope	Vertical slice	These methods produce a prototype that explores one aspect of the design in depth.
	Horizontal slice	These methods produce a prototype that explores one entire level of the design with limited depth.
	Full scope	These methods produce a prototype that explores the full scope of the design.
Purpose	Experiment	These methods are used to compare and narrow options.
	Validate	These methods are used to test whether implementation works as expected.
	Explore	These methods are used to generate more options.
	Persuade	These methods are used to convince a client of the feasibility of a project before starting major work on it.
	Demonstrate	These methods are used to provide concrete examples to help anchor a discussion about the design

**Fig. 5.** Sample concept generation half-sheet with annotation for method used.

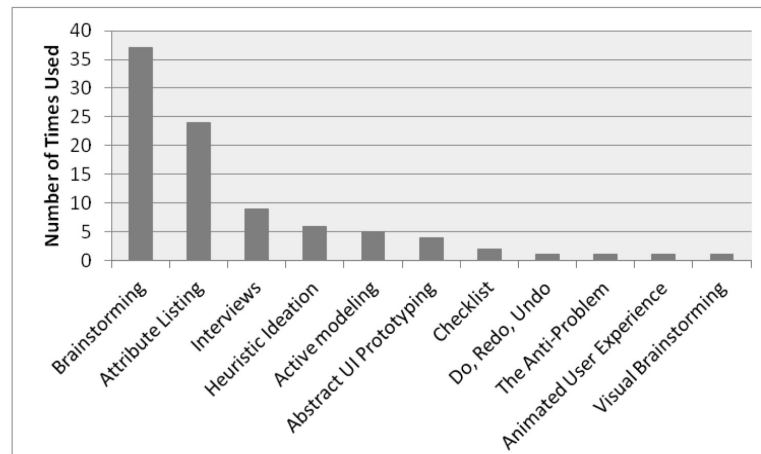


Fig. 6. Methods used for the half-sheet concept generation exercise that are in *theDesignExchange*.

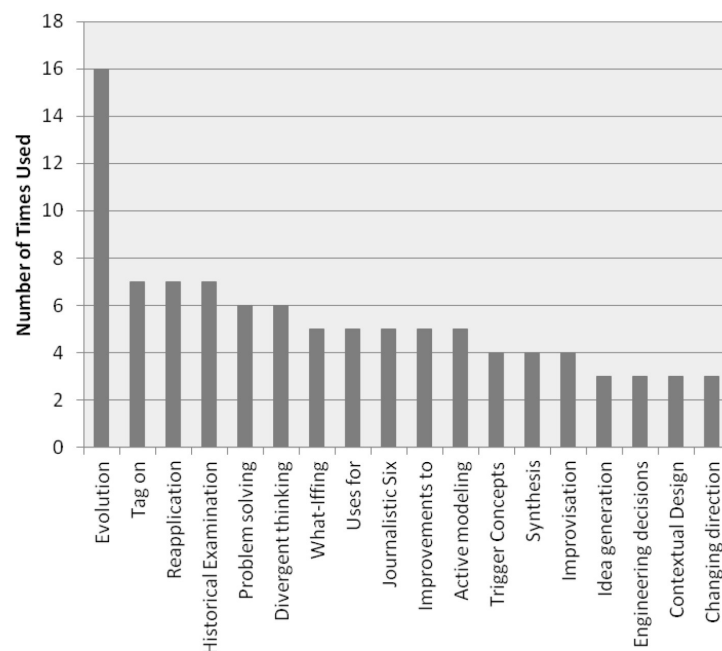


Fig. 7. Methods used for the half-sheet concept generation exercise that are not in *theDesignExchange*.

typing and testing, students were given the post-survey on creative confidence [24]. As a class overall, the students' self-assessments increased significantly from 49.4 points to 54.7 points on average between the pre- and post-creativity tests (student t-test, p -value <0.001). For example, students who selected "not at all" for the statement "I often ignore good ideas because I do not have the resources to implement them" earned 5 points while "very often" only earned 1 point. In the pretest, the average score for that question was 2.7; the average post-test increased significantly to 4.2 (student t-test, p -value <0.001).

6.3 Ideation and Early Prototyping Module

Five students completed the ideation and early

prototyping module. Each completed module was assessed against the rubric and found to be of sufficient detail and quality to be worthy of an Ideation and Early Prototyping Badge. They reported encountering an average of seven new ideation methods on *theDesignExchange* that they had not known previously (min = 3, max = 13). It is notable that all five submissions referenced the value of various ideation methods as a tool for enabling design understanding beyond the individual designer. This broader external understanding could be among the members of the student's project team, as noted by one student who said of brain-writing: "Since our team is prone to either the loudest people talking or the more task-conscious people, this way we can make sure everyone partici-

pates.” This understanding also extended to their project’s larger market of users. A student said that brainwriting “seems like it would be an effective way to bridge the gap between different cultures as well,” while another one states, “we’ve been taking a very narrow approach to our project, without considering the impact our concepts can make on a global scale. . . . I think Forced Analogy would have taken us outside of the box, as well, since we kept thinking of daily items very literally.” Similarly, the students discussed their thoughts on early prototyping methods, and the underlying theme was once again that of using methods to guide the team, not just an individual, to better outcomes by reaching and connecting with users. In particular, one student noted that prototypes are valuable because they “better allow our group to get a sense of what direction we are trying to pursue (such as the Create Frameworks method) and . . . the physical products we can have to engage potential customers . . .”

7. Conclusions and future work

This paper summarizes the findings of practitioner workshops on ideation and prototyping, including lists of the categories of methods identified, based on a qualitative analysis of the conversations that were held. Based on our insights from expert/novice differences, future work will be directed towards methods for which *theDesignExchange* could be used to achieve levels of proficiency in use of early stage design methods.

Implications for enhancing professional skills, industry practice and design education must consider that the typical design curricula faces time constraints that limit the number of design methods that can be taught in any individual course. This leaves students and young practitioners with few methods in their toolbox. However, interactive repositories such as *theDesignExchange* present the opportunity to expose students to a far larger space of possible design methods and allow them to pursue learning about design tools beyond their formal classroom education. Results from classroom experiments complementing formal design education with online educational modules associated with *theDesignExchange* highlight the need to expand the number of methods included. Findings from the online educational modules further suggest that learning about new methods from *theDesignExchange* enables students to think beyond themselves, and consider how to engage in design with their own teams and within the larger communities for which they are designing.

Acknowledgements—The authors wish to thank our industry collaborators who hosted our workshop series: Autodesk, Frog, Goto Media, DesignMap, and IDEO and our team of

faculty and students at UC Berkeley and MIT for their input and dedication to *theDesignExchange*. This work was partially supported by NSF grant CMMI-1334361.

References

1. P. G. Rowe, *Design Thinking*, MIT Press, Cambridge, MA, 1991.
2. T. Brown, Design Thinking, *Harvard Business Review*, **86**(6), 2008, pp. 84–92.
3. T. Brown, *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*, Harper Collins Publishers, New York, NY, 2009.
4. S. Portigal, *Interviewing Users: How to uncover compelling insights*, Rosenfeld Media, New York, NY, 2013.
5. S. Beckman and M. Barry, Innovation as a Learning Process: Embedding Design Thinking, *California Management Review*, **50**(1), 2007, pp. 25–56.
6. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey and L. J. Leifer, Engineering Design Thinking, Teaching and Learning, *Journal of Engineering Education*, **94**(1), 2005, pp. 103–120.
7. H. Gedenryd, *How designers work*, vol. 75, Lund University, 1998.
8. J. C. Jones and D. Thornley, (Editors), *The Conference on Design Methods: papers presented at the conference on systematic and intuitive methods in engineering, industrial design, architecture and communication*, Pergamon Press, London, 1962.
9. J. Kolko, *Exposing the Magic of Design: A Practitioner's Guide to the Methods and Theory of Synthesis*, Oxford University Press, 2010.
10. B. Martin and B. Hanington, *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*, 2012.
11. T. Plowman, Ethnography and critical design practice. In *Design research: Methods and perspectives*, MIT Press, Cambridge MA, 2003, pp. 30–38.
12. L. Sanders, An evolving map of design practice and design research, *Interactions*, Vol. 15.6, ACM, 2008, pp. 13–17.
13. C. Roshuni, J. Kramer, Q. Zhang, L. Zakskorn and A. M. Agogino, Design Talking: An Ontology of Design Methods to Support a Common Language of Design, *Proceedings of the International Conference on Engineering Design, ICED15*, 2015.
14. M. Buchenau and J. F. Suri, Experience prototyping, *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques*, New York, NY, USA: ACM, 2000, pp. 424–433.
15. T. Mattelmäki and K. Battarbee, Empathy Probes, *Proceedings of the Participatory Design Conference*, Malmö, Sweden, 2002.
16. ParticipationCompass, <http://participationcompass.org>, Accessed Sept. 19, 2015.
17. Service Design Tools, <http://www.servicedesigntools.org>, Accessed Sept. 19, 2015.
18. IDEO, Design Kit: the Field Guide to Human-Centered Design, <http://www.ideo.com/work/human-centered-design-toolkit/>, Accessed Sept. 19, 2015.
19. LUMA Institute, <https://hbr.org/2014/01/a-taxonomy-of-innovation>, Accessed Sept. 19, 2015.
20. D. Gray, *Gamestorming: A Playbook for Innovators, Rule-breakers, and Changemakers*, O'Reilly Media, Inc, Sebastopol, CA, 2010.
21. B. Hartmann, *Gaining Design Insight Through Interaction Prototyping Tools* (PhD). Stanford University, 2009.
22. C. Roshuni, J. Kramer, A. M. Agogino, Design Talking: How Design Practitioners Talk About Design Research Methods, *Proceedings of the International Conference on Design Education, IDETC15*, 2015.
23. L. Oehlberg and A. M. Agogino, Undergraduate conceptions of the engineering design process: Assessing the impact of a human-centered design course, *ASEE Proceedings of the Annual Conference and Exposition*, 2011.

24. Mindtools, <http://www.mindtools.com/pages/article/creativity-quiz.htm>, Accessed Sept. 19, 2015.
25. T. Kelley and D. Kelley, *Creative confidence: Unleashing the creative potential within us all*, Crown Business, 2013.
26. DesignMap, <http://DesignMap.com/swarm>, Accessed Sept. 19, 2015.

Alice M. Agogino is the Roscoe and Elizabeth Hughes Professor of Mechanical Engineering and is affiliated faculty at the Haas School of Business at the University of California at Berkeley. She currently serves as Chair of the Graduate Group in Development Engineering housed in the Blum Center for Developing Economies. She directs research in the BEST (Berkeley [Energy and Sustainability Technologies/ Expert Systems Technologies/ Emergent Space Tensegrities]) Lab and co-directs the Berkeley Institute of Design, the Human-Centered Design course threads for undergraduates and the Engineering and Business for Sustainability graduate certificate program. She works with approximately 50 San Francisco Bay Area companies and nonprofits on research and educational projects in product design and sustainability. Agogino received a B.S. degree from the University of New Mexico (1975), M.S. degree from UC Berkeley (1978) and Ph.D. from Stanford University (1984).

Sara Beckman is the Earl F. Cheit Faculty Fellow at the Haas School of Business where she designs and delivers courses on design, innovation and product management. Her 25 years of experience teaching design and innovation-related topics culminated in creating a course, Problem Finding, Problem Solving, which draws from design thinking, critical thinking and systems thinking literature. That course is now offered to all business students at UC Berkeley. Her recent research focuses on the role of learning style diversity on design teams, and on the pedagogy of teaching design. Before joining Berkeley-Haas, Sara worked in the Operations Management Services group at Booz, Allen & Hamilton and ran the Change Management Team at Hewlett-Packard. Sara received her B.S., M.S. and Ph.D. degrees from Stanford University in Industrial Engineering and Engineering Management.

Carmen Castaños has a S.B. in Civil Engineering and an M.S. in Mechanical Engineering at M.I.T. and earned her S.B. in Civil Engineering from M.I.T. Her interests include product design, creativity in engineering, and structural design.

Julia Kramer is a Ph.D. graduate student in Mechanical Engineering at the University of California, Berkeley. She has a B.S.E. in Mechanical Engineering from the University of Michigan and M.S. in Mechanical Engineering from UC Berkeley. Her research interests include creativity and innovation in engineering, the intersection between engineering education and design, and the investigation of local users and stakeholders through ethnographic data collection.

Celeste Roschuni is a design and user research professional, who also teaches at the University of Maryland in the Mechanical Engineering department. Her primary research interests are in the early stage product development and innovation, design methods, and the design community of practice. She holds a Ph.D. (2012), M.S. (2009) and B.S. (2003) from the University of California at Berkeley.

Maria Yang is an Associate Professor of Mechanical Engineering at MIT. Her research is in the preliminary phases of the process of designing both products and complex engineering systems, with a focus on the role of design representations. She teaches project-based product design and development courses for students from freshman to graduate-level. She is an ASME Fellow, and the recipient of the ASEE Merryfield Design Award, the MIT Spira Teaching Award, the MIT MacDonald Mentoring Award, and the MIT Earll Murman Undergraduate Advising Award. She earned her SB in Mechanical Engineering from MIT, and her M.S. and Ph.D. from Stanford.