

The Design Problem Framework: Using Adaption-Innovation Theory to Construct Design Problem Statements

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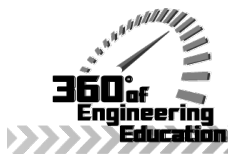
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Abstract

Ideation is the process of generating ideas for solving design problems, and it is a critical part of the overall design process. In order to encourage designers to ideate across a broader spectrum of ideas, we developed the Design Problem Framework (DPF) to assist in the development and framing of design problem statements. Part of the basis for the DPF was research on cognitive styles, which suggests that there is a range of preferences for approaching problem solving, and that these preferences influence how different individuals naturally approach ideation. We used Kirton's Adaption-Innovation theory as a basis for understanding the range of cognitive styles. The other part of the basis for the DPF was research on problem framing, which suggests that the structure of design problem statements influences an individual's approach and the outcomes produced. Using the DPF as a foundation, we propose that design problems that encourage adaptive ideation behaviors include more specified constraints, along with criteria for solutions that build on already existing solutions to the same or similar problems. In contrast, design problems that encourage innovative ideation behaviors include criteria for solutions that are radically different from existing solutions and are not bound by specific constraints. In this paper, we present a set of five design problems constructed using the DPF, with three different versions of each problem statement: (1) a neutrally framed version; (2) an adaptively framed version; and (3) an innovatively framed version. Three examples of student-generated solutions are also discussed to illustrate the resulting outcomes. We propose this framework as a guide for the development of design problem statements for use in education, research, and the workplace.

Introduction and Background

What is the primary problem solved by this framework?

The way a problem is structured and perceived by designers impacts the resulting outcomes, whether the context is education, research, or the workplace. In the workplace, the presentation of a problem supports understanding and communication regarding the expectations of the client and the approach taken by the designers.¹ In addition, the wording of a problem statement can enhance or limit whether individuals with diverse expertise see their varied experiences and knowledge as relevant.² In research on how engineers generate ideas to solve design problems, the choice of a single design problem is typically justified for a particular study, but rarely is there an explicit test of how the choice or presentation of that problem influences or biases the outcomes observed. In education, engineering instructors have the ability to create and select design problems in their instructional activities. However, the path for choosing problem statements (or guiding students to develop their own) that lead toward certain types of solutions (e.g., readily implementable, radically different than existing solutions) is not well defined. Whatever the setting, the framing of the design problem is rarely given the same attention as the actual implementation of the design process. Word choices, decisions about relevant information to include, and stated goals within these design problem statements are likely to impact approaches to generating solutions, as well as the design solutions themselves. Thus, as we seek to improve design skills and outcomes, we must focus on this critical element of the design process.

Our goal is to better understand how the framing of design problems can influence the types and ranges of solutions that individuals are likely to generate. Although we believe this understanding has benefits in workplace, research, and education settings, we start from the perspective of engineering education. In engineering design courses, there may be diversity in students' own preferences for approaching design tasks, but there may also be an influence of the design problem itself on encouraging certain types of solutions over others. Dorst³ suggests that much of design research has focused on the design process, but it has paid comparatively less attention to the other two dimensions of design activities, namely, the designer and the design task. In this work, we provide a structure to guide instructors in thinking more explicitly about how design problems are constructed and presented, so they can make more informed decisions about the types of problems they give to their students.

A major goal of our larger research project is to provide engineering instructors with a set of tools that they can use to improve their students' ideation approaches and outcomes.⁴ Whereas ideation is the process of generating ideas for solving design problems, ideation flexibility is the ability of individuals to approach ideation in different ways. We are specifically interested in helping designers to flexibly adopt ideation approaches that result in ideas either representing radical change or incremental change (or both) depending upon the situation.⁵ One of the tools we are developing to enhance ideation flexibility is called the Problem Framing Profile (PFP). Different framings of a design problem may highlight the importance of different aspects within the problem, and so may encourage different approaches for solving the problem and different design outcomes. The PFP will provide a mapping between problem framing characteristics and anticipated ideation processes and outcomes. As a first step towards developing the PFP, we sought to better specify a process for creating design problems, and then for manipulating those design problems into different problem framings. We integrated Adaption-Innovation (A-I) theory⁶ with literature on design and problem solving to build a framework intended to serve as a guide for the development and framing of design problems, called the **Design Problem Framework (DPF)**.

In this paper, we present the development of the DPF and five example design problem statements that we generated by applying the DPF. We also present examples of ideation solutions in different framings of one of the design problems. In future work, we will explore our larger population's design outcomes using these problems, which will serve as a more comprehensive test of the validity of the DPF.

What prior research informs this framework?

A common way to think of a design problem is as a search task.⁷ The designer must engage in a search of different possible ideas in order to ultimately select (and implement) the one idea that they believe will effectively solve the design problem. The set of all possible ideas is often referred to as the design space,⁸ and so the designer's goal is to search through the design space. An ideal strategy might be for the designer to develop some method for exhaustively searching the entire design space, thus guaranteeing that the designer will be able to locate an optimal solution. However, for most design problems, an exhaustive search is not feasible. This is because design problems are underdetermined and ill-structured,^{3,9} so the design space may be extremely large, and characterizing its dimensions or boundaries may be difficult. As a result,

designers must use different strategies or approaches to search the design space for potential ideas to consider.

In most cases, generating only one idea for a design task is unlikely to be an effective strategy. Novice designers are likely to make this mistake of generating only one idea,¹⁰ but even more experienced designers may fixate on a particular idea without considering a wider range of alternatives.^{11,12} Research on ideation suggests that an ideal approach includes at least some divergent thinking, in which the designer deliberately expands their search space in order to consider multiple and diverse alternative ideas.¹³

Since design problems are constrained but still underdetermined, designers may be influenced by how the design problem itself is framed. That is, even given the same underlying problem, differences in how the problem is presented to designers may impact how they approach generating alternative ideas to solve that problem.^{14,15} For example, research on creative idea generation suggests that providing examples to the designer may unintentionally constrain the thinking of the designer and thus limit the types of ideas they generate.^{16,17} However, in engineering design, when examples are chosen carefully, they can serve to broaden the solution space used to generate alternative ideas.^{18,19}

Another way to consider the effect of framing on a designer's ideation approach is in terms of goals.^{20,21} For example, a goal to "do your best" generally produces less effective performance than a more specific and difficult goal, since it may be hard to understand what a good job looks like in a specific situation. In idea generation, researchers have found an improvement when including instructions for generating a specific number of ideas ("generate 30 ideas") versus a vague quantity goal ("generate as many ideas as you can").²² But quantity is not the only goal that can be manipulated, as instructions to come up with "creative" ideas²³ or "novel" ideas²⁴ can also influence the types of ideas that designers generate.

Finally, framing focuses primarily on differences in the way the problem is presented, but how different individuals interpret that framing can vary considerably. Person-situation fit theory suggests that individual factors and problem factors may work together to influence one's approach to idea generation in a particular problem. For example, O'Hara and Sternberg²⁵ review the literature on explicit instructions to be creative, and suggest that although there does appear to be a main effect of instructions on improving the quantity and proportion of creative responses, there may be an interaction with participants' thinking styles. They describe a situation in which a task has "neutral instructions" and so does not explicitly specify what types of ideas to generate. In this case, individuals may rely on their habitual strategies. Explicit instructions may serve to "disambiguate" the situation, which may then enable individuals to break out of their habitual or dominant responses in favor of a strategy that is better suited to the particular situation. Thus, a framework for understanding different ways to present design problems should take into account a number of factors related to idea generation, including both how the problem is framed and how different individuals might respond to those different framings.

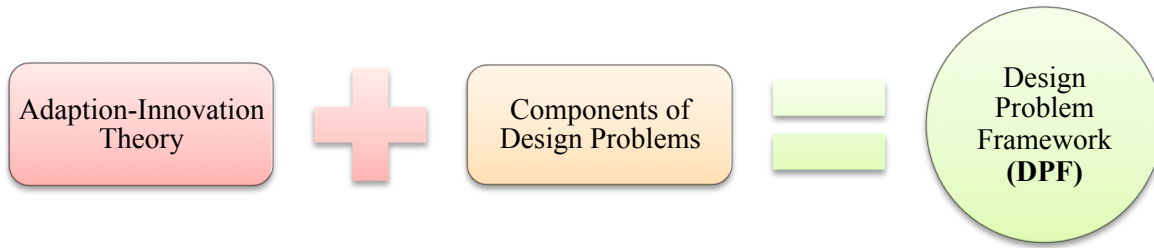


Figure 1. The basis for the Design Problem Framework (DPF).

The Design Problem Framework

We developed the DPF by identifying connections between Adaption-Innovation (A-I) theory and components of design problems (Figure 1). Below, we first review A-I theory and its role in specifying a continuum of cognitive styles that correspond to different ways to approach idea generation for design problems. Then, we review literature on the components of design problems, such as the context, the need, and the goals. Finally, we suggest how those components can be manipulated such that they are likely to encourage individuals to take on these different approaches for generating ideas to design problems.

Adaption-Innovation (A-I) Theory

Kirton's Adaption-Innovation (A-I) theory⁶ describes the different ways people respond to and seek to bring about change through problem solving, as well as how they prefer to manage structure within those scenarios. A-I theory suggests that individuals' problem solving preferences (also called cognitive style) can be described on a continuum from more adaptive to more innovative. The term "innovative" here does not refer to people who are generally good at generating creative ideas. A-I theory posits that both more adaptive and more innovative cognitive styles lead to ideas that are creative. Rather, as explained below, the term simply describes their particular preference for approaching problem solving. A-I theory is well suited for researching design ideation, as research with A-I theory has revealed three factors that comprise an individual's overall cognitive style, one of which specifically relates to idea generation. This factor is labeled Sufficiency of Originality versus Proliferation of Originality (SO/PO). The SO/PO factor refers to how individuals across the spectrum prefer to generate ideas in different ways. Some typical characteristics that distinguish more adaptive and more innovative individuals on the SO/PO factor are summarized in Table 1.

According to A-I theory, individuals who are more adaptive prefer more structure and try to "make things better" by generating solutions that fit within consensually agreed constraints. Ideas that fit within the prevailing paradigm of the problem are called paradigm preserving,²⁶ and more adaptive individuals tend to produce mostly ideas of this type. In contrast, individuals who are more innovative prefer less structure, try to "do things differently", and are more likely to generate ideas that do not fit within established constraints. Ideas that do not fit within the established boundaries of a problem are called paradigm modifying, and more innovative individuals are more likely to generate ideas of this type. Kirton²⁷ describes how more innovative individuals may generate some ideas that are paradigm preserving and some ideas that are

paradigm modifying, since more innovative individuals have looser regard for the boundaries and are less likely to know when they have crossed them (or not). More innovative individuals also tend to generate more ideas, realizing that many of those ideas may ultimately be discarded, but proliferating ideas may lead to one or two ideas that pay off in the long term. Because many of the ideas generated by more innovative individuals do not build on existing solutions, their ideas are less likely to be as straightforward to implement. Of course, even if paradigm-modifying ideas are often challenging to implement, this is not always the case. On the other hand, more adaptive individuals may produce fewer ideas (by choice, not by capacity), but most of their ideas tend to be sound and more immediately useful for the given problem. Because many of the ideas generated by more adaptive individuals build on existing solutions, their ideas are often (although not always) more immediately implementable.

Table 1. Some typical characteristics of more adaptive and more innovative individuals relevant for design ideation (adapted from Kirton²⁷, p. 55).

	<i>More Adaptive Individuals</i>	<i>More Innovative Individuals</i>
<i>Problem Defining</i>	More adaptive individuals tend to accept the problems as defined by consensus, accepting generally agreed constraints. Early resolution of problems, limiting disruption, and immediate increased efficiency are their more important considerations.	More innovative individuals tend to reject the generally accepted perception of problems and redefine them. Their view of the problem may be hard to get across. They seem less concerned with immediate efficiency, looking to possible long-term gains.
<i>Solution Generating</i>	More adaptive individuals prefer to generate a few novel, creative, relevant, and acceptable solutions aimed at ‘doing things better.’ They have confidence in implementing solutions effectively, despite size and complexity.	More innovative individuals generally produce numerous ideas, some of which may not appear relevant or be acceptable to others. Such ideas often contain solutions which result in ‘doing things differently’.

One central tenet of A-I theory is that cognitive style is independent of cognitive level, where level refers to an individual’s current capacity to solve particular types of problems. Cognitive level may be the result of an individual’s familiarity with a particular problem solving context, or may be related more generally to the skills and expertise the individual has developed. In the case of ideation, cognitive level may refer to an individual’s capacity to generate ideas that are creative and likely to be effective. A-I theory distinguishes between level and style, and so individuals all across the continuum of more adaptive to more innovative have the capacity to generate creative and effective ideas.

A-I theory is grounded in the premise that neither an adaptive nor an innovative cognitive style is generally better than the other. Instead, more adaptive solutions may be appropriate for some situations and more innovative solutions may be appropriate in others. In many situations, it may be best to consider solutions of both types. While more adaptive individuals are more likely to generate paradigm-preserving ideas, those solutions are just as likely to be considered novel as solutions generated by more innovative individuals. Ideas developed by those with more

adaptive cognitive styles are often developed in a way that builds on existing solutions, but are not necessarily ways that have been considered before. Also, a paradigm-preserving idea is not guaranteed to lead to an effective solution even though it builds on existing ways to solve the problem. Similarly, people with more innovative cognitive styles are not more likely to have novel or “creative” solutions, but the novelty of their ideas is often based on the premise of shifting the way the problem is viewed or suggesting solutions outside of existing approaches to solving the problem.

In the general population, individuals fall along the entire continuum from more adaptive to more innovative in a normal distribution.²⁷ Although individuals have a preferred cognitive style, they are capable of working in ways that are not preferred through coping behavior,⁶ which comes at a greater cognitive cost. The DPF (Design Problem Framework) seeks ways to encourage individuals, regardless of where they fall along the A-I continuum, to either approach a problem with their own preferred style, or to adopt coping behavior to take on a solution approach that is more adaptive or more innovative than their natural preference would dictate.

Design Problems

Design problems are usually open-ended and ill-structured,^{28,29} but each design problem includes some bounds and structure that helps clarify the problem. Based on our personal experiences with formulating design problems in our research and in our teaching, we have found that well-formed design problems include at a minimum the following three components: (a) brief **context** about for whom and for what purpose a solution is needed, (b) a statement of the **need** that specifies the functional requirements and constraints on acceptable solutions, and (c) a description of the **goal**, including the general instructions and criteria to use in evaluating ideas. Although the three components may not be the only way to organize design problem statements, we have found them to be consistent with design texts,^{28,29} as well as what other design researchers have used in their own work. For example, Cross, Christiaans, and Dorst conducted protocol studies in which they used a design brief for a problem to design a litter-disposal system for a railway car.^{30,31} Their design brief included short statements about the various stakeholders involved, an outline of the problem itself, and the role of the participant.³⁰ As another example, Linsey et al.^{32,33} conducted a series of studies on idea generation using a problem to design a device to quickly shell peanuts. The problem description included statements about the countries that would particularly value such a device, why automating the process would be helpful to people in those countries, a list of the requirements and constraints for the device, and some instructions to the participant about their goal for the activity. These three components of design problems that are considered essential in the DPF are summarized in Figure 2.

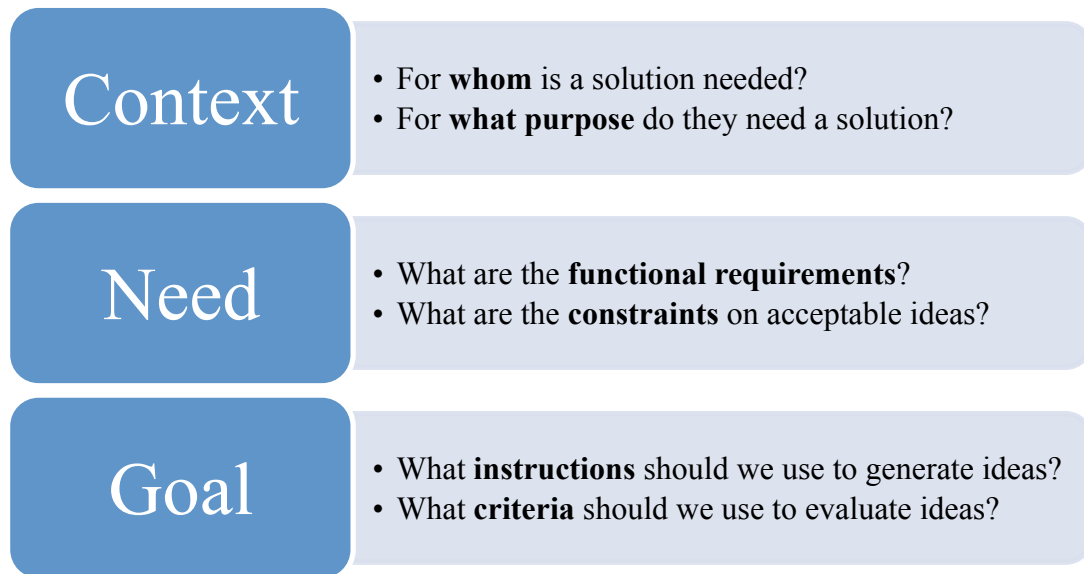


Figure 2. Three essential components of design problems in the DPF.

Context

The first essential component of a design problem statement in the DPF is context. Jonassen³⁴ defined three general classes of problems: puzzle problems, well-structured problems, and ill-structured problems. These three classes fall along a continuum from puzzle problems that are decontextualized and have a single, known solution, to ill-structured problems that are deeply embedded in a context and have multiple acceptable solutions. In most cases, design problems fit into the ill-structured category,^{28,29} as there is usually some ambiguity and no single answer. For this reason, in contrast to decontextualized puzzle problems, the context is crucial in helping the designer to fill in the missing or implicit information and to choose among alternative ideas they are considering. As a result, in the DPF, there must be some context specified in the problem statement that describes for whom and for what purpose a solution is needed. Interestingly, understanding the context is an essential part of authentic design activities.³⁵ However, our work is focused on the part of the design process where designers have already explored and included these issues and are now focusing on generating possible solutions. Including a context in the problem statement does not mean that participants would be precluded from questioning or reframing that context. Indeed, expert designers are more likely than novices to challenge contextual information given in a problem statement, identify aspects that may be inaccurate or inadequate, and to infer characteristics that will help with their problem solving.^{36,37} As a result, understanding the context remains an important part of an effective idea generation process in problem statements structured using the DPF.

Need

The second essential component of a design problem statement in the DPF is the need. General descriptions of engineering design stress the importance of identifying functions that the design must perform.^{28,29} These functional requirements are then written in a concise way as a needs statement, which serves as the most basic formulation of the design problem. An important part

of formulating the need in terms of functions is to avoid tying the function to a particular solution. For example, a designer may be given the task to design a way for an individual to stay dry while walking to work. It might be tempting for the instructor to include a specific solution idea in the problem statement, such as an umbrella, but doing so is likely to encourage the designer to fixate on solutions that are similar to umbrellas and not consider alternative ideas that could take advantage of very different means for meeting the same need. We call these suggestions to particular solutions, “implied solutions,” and make every attempt to exclude them in needs statements generated using the DPF. Fricke³⁸ has found that more successful designers are able to suppress initial solution ideas when they are initially trying to understand the problem, and are effective at reconsidering the problem a number of times in a “solution-neutral formulation of the requirements” before beginning their search for a solution. In the DPF, the functional requirements are always specified in a way that focuses on the primary need that the solution must meet rather than on any particular solution.

Goal

The final essential component of a design problem statement in the DPF is the goal. General goal-setting theory^{20,21} highlights the importance of goals for directing and sustaining an individual’s effort in problem solving. The goal can be as simple as telling the designer to generate solutions to the design problem, or it can include additional information about the process that the designer should use for generating those ideas. Litchfield^{22,39} advocates the view that in idea generation, it may be more appropriate to think of common ideation rules (such as the rules used in brainstorming) less as a process and more as a set of goals. Doing so allows the instructor or researcher to be more specific about the criteria that individuals should use when generating their ideas and evaluating whether or not they have satisfied those goals.

In addition to the three basic parts of a design problem (context + need + goal), many design problem statements also include two additional parts: (d) constraints that all acceptable solutions must satisfy, and (e) criteria to distinguish the types of solutions that will be valued most highly. In the DPF, constraints and criteria are part of the need and the goal.

Constraints

Constraints are included in design problems based on situational concerns to place boundaries on the design space. Constraints may include limitations on the size, weight, or cost of the solution, among other considerations. Constraints in design problems are often found in the needs statement, but should be distinguished from functional requirements. Although functional requirements are in some sense a form of constraint, the functions are really the primary reason for the problem. Goel and Pirolli⁸ suggest that other constraints are rarely, if ever, necessary in an absolute sense. Instead, design problem constraints have the property of being negotiable and changeable. A designer can justify relaxing a constraint if doing so may lead to a solution that is in some way more effective or desirable.

Criteria

Criteria are also an important part of design problems. Similar to constraints, criteria help to place boundaries on the design space by suggesting what characteristics of solutions might be

most valued. An example of a common criterion is cost. Although cost could certainly be presented as a constraint (e.g., the solution should not exceed \$15), cost may also be presented as a criterion (e.g., the less expensive the solutions the better). Other criteria may include suggestions about the type of solution, such as one that is very different or radical relative to existing solutions compared to solutions that build on and improve existing solutions. There are many possible criteria for evaluating ideas,⁴⁰ but those related to quality, novelty, and creativity are commonly included in design problem statements. Criteria can be found in both the need and the goal components of the problem statement.

In summary, the context, need, and goal make up the essential components of design problem statements in the DPF. After these are developed for a particular design problem, the DPF then suggests ways to frame the design problem in different ways to encourage different solution approaches by manipulating the constraints and criteria of the problem.

Framing Design Problems

For every design problem, we generate three different frames using the DPF: neutrally framed, adaptively framed, and innovatively framed. The neutral frame is intended to encourage individuals to approach the design problem from their natural or preferred solution approach. The neutral frame consists of the initial specification of the context, need, and goal for a particular problem, and it is then used as the basis for the other framed problems. The adaptively framed problem manipulates the need and the goal of the neutrally framed problem so that the designers are encouraged to generate ideas that build on and improve existing ideas. In contrast, the innovatively framed problem manipulates the need and the goal of the neutrally framed problem in a way that encourages the designers to generate ideas that are tangential to and very different from existing ideas. Figure 3 summarizes the different framings of design problems in the DPF.

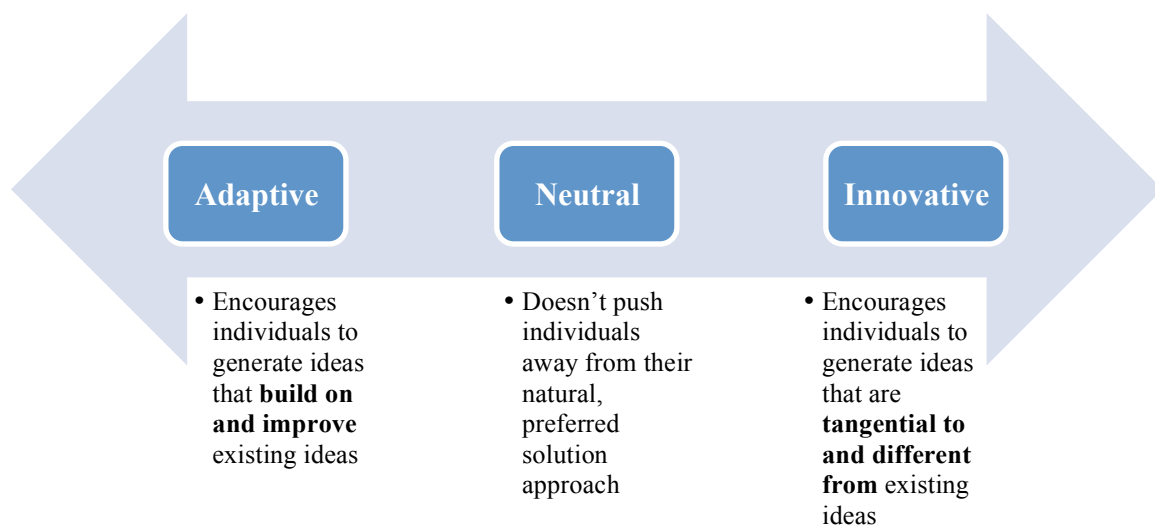


Figure 3. The three different problem frames in the DPF.

What is in a neutrally framed problem statement?

The neutrally framed problem statement begins with the initial specification of the context, need, and goal for the design problem. Although in some sense a neutrally framed problem statement suggests an absence of a frame, thinking this way may lead to unintentional framings. For example, when setting up students to generate ideas for solving a design problem, an instructor may provide many details about specific evaluation criteria of acceptable solutions. The instructor may state in the goal of the problem statement that the ideas should be practical and immediately workable. Alternatively, the instructor may write that they want creative ideas. If the instructor's goal is to limit ideas in one of these ways (i.e., immediately workable solutions or creative solutions), then it is fine to add such criteria to the goal. However, it is important to recognize that doing so may inadvertently discourage students from broadening their search of the solution space. In developing the DPF, we were careful to recognize necessary or essential elements of design problem statements. We include the context, the need, and the goals for the problem, but do not elaborate on additional constraints or criteria that might have some value but would not be strictly necessary for a solution.

Why not include (or vary) any sort of quantity goal (specific quantitative or general)?

One thing that the neutrally framed problem statement does not do is encourage the designer to use an ideation approach that may be inconsistent with their natural ideation approach as related to their cognitive style.²⁷ Advocating that designers generate many ideas has sometimes been considered a best practice in the literature, using the reasoning that generating a greater quantity of ideas will likely lead to generating a greater number of high quality ideas.^{41,42} This is especially important in the context of novice designers, who are likely to fixate on only one or a few ideas without critically examining them.¹⁰⁻¹² However, research on more experienced designers suggests that a balanced search for ideas may be the most effective.^{38,43} That is, generating only one idea or very few alternatives is an “unreasonable restriction” of the search space,^{38,43} but there are also diminishing returns from generating too many ideas.⁴⁴ As a complicating factor, there may be an effect of an individual's experience level with a particular problem type or domain that allows some expert designers to be effective taking a solution-focused approach to a problem, but that may not be easy for a novice designer or someone with less domain-specific experience to implement.⁴³ Thus, even though generating a single idea is likely not ideal for most design problems, the optimal number of ideas to generate may depend on the designer's level of experience with the particular problem. Ultimately, for our purposes in the DPF, it was important in the neutral framing not to bias individuals towards generating many ideas or just a few ideas, since their natural approach may lead them one way or the other.²⁷ Even in the framed problem statements, we do not instruct the designers to generate a particular quantity of ideas. Although more adaptive individuals may naturally choose to generate fewer ideas, and more innovative individuals may naturally choose to generate a greater number of ideas, the framings in the DPF intentionally leave that choice open to the designer. Instead, in the DPF, individuals are instructed to generate “ideas” (in the plural form) and to “continue working for the full time of the activity” without making a suggestion about the ideal quantity of ideas.

What is in an adaptively or innovatively framed problem statement?

The neutrally framed problem provides a base problem statement from which to generate both an adaptively framed and an innovatively framed problem statement. The neutrally framed problem statement encourages the designer to generate ideas using their own preferred style and approach. An individual may prefer to generate ideas that are more adaptive or more innovative, or some of both. The goal of the adaptively and innovatively framed problems is to encourage designers to direct their ideation approaches in a particular way. So, the adaptively framed problem will encourage the designer to generate more adaptive solutions that build on and improve existing solutions and common ways of thinking about the problem. These more adaptive solutions may be consistent with a more adaptive individual's preferred ideation approach, but may be less consistent with a more innovative individual's preferred approach. The innovatively framed problem will encourage the designer to generate more innovative solutions that include different solutions that break with convention of typical ways to think about the problem. Again, these more innovative solutions may or may not be consistent with an individual designer's preferred approach. The innovatively and adaptively framed problems make use of constraints and criteria to encourage the designer to generate more ideas of either the innovative or adaptive type, respectively.

What is the potential impact of varying the constraints?

In terms of constraints, more adaptive solutions may be more likely to be generated when the number of specified constraints is higher. For example, going back to the task of designing a way for an individual to stay dry while walking to work, someone might come up with a complex idea that involves building elaborate covered walkways. However, if the constraint is imposed that all solutions should be able to be carried by each individual, then that would effectively exclude the covered walkway idea. Common constraints may be related to cost, size, and weight, but would also be dependent upon the particular context of the problem. In contrast, explicitly instructing an individual not to consider constraints such as cost, size, or weight in the ideas that they generate may encourage the individual to come up with more innovative ideas. As a result, the innovatively framed problem statements explicitly mention constraints that the designer should be careful not to use to limit their search.

What is the potential impact of varying the criteria?

In terms of criteria, more adaptive solutions and more innovative solutions are contrasting in terms of a number of characteristics. One prominent characteristic is the expectation of novelty,⁴⁵ such that adaptive solutions are more likely to improve existing or familiar designs (one type of novelty), while innovative solutions are more likely to introduce unexpected features or functions (a different type of novelty). The instructions to the designer can explicitly encourage solutions of either type. Other descriptors could include "practical" versus "radical" solutions, which could be used to differentiate the problem framings. Another common way to distinguish more adaptive and more innovative solution approaches is in terms of immediate efficiency. More adaptive solutions may be easier and less costly to implement immediately, because they take advantage of existing or common aspects of the typical environment. In contrast, more innovative solutions may be harder, costlier, or riskier to implement right away, since they may depend on a whole new way of approaching the problem. Statements that explicitly tell the

designer to factor either more adaptive or more innovative criteria into their ideation approach may encourage them to generate ideas of that type.

Why not include (or vary) explicit constraints (only include general constraints)?

The problem statements in the DPF only include general constraints in both the adaptively and innovatively framed versions. To use an illustrative example of what we mean by this, Table 2 summarizes the options for considering weight as a constraint in a design problem statement. Consider first an adaptively framed problem. In the DPF, adaptively framed problems include one or more explicit constraints on the type of solution. One way to include an explicit constraint is to use specific quantitative values, such as, “The solution should weigh less than 15 pounds” (bottom left box in Table 2). An alternative way to include an explicit constraint is more general, such as “Consider constraints such as weight in your solution” (top left box in Table 2). In both cases, the adaptively framed problem includes the explicit constraint of weight, which potentially helps designers to limit the ideas they generate to more adaptive ones.

Table 2. An example constraint varied by specificity and inclusion.

		Constraint Inclusion	
		<i>Included (Adaptively framed)</i>	<i>Excluded (Innovatively framed)</i>
Constraint Specificity	<i>More General</i>	Consider constraints such as weight in your solution.	Don't be concerned about a particular weight of your solution.
	<i>More Specific</i>	The solution should weigh less than 15 pounds.	?

However, in the innovatively framed problem statements, the designers are encouraged explicitly not to consider particular constraints when generating ideas. Instructing the designer to not be concerned with a particular constraint is fairly straightforward when using the language of general constraints (see the top right box in Table 2). It is not clear how to write the equivalent innovatively framed statement for excluding a specific constraint. As a result, the DPF includes only the more general constraints in the framed problem statements. This way the contrasting framed problem statements vary only in the presence or absence of the constraint and not on the level of specificity of the constraint. Varying on only one feature is especially important when using the adaptively and innovatively framed problem statements in controlled experiments. However, there are likely situations in education or workplace settings in which using more specific constraints are warranted.

Example Design Problem Statements

In order to illustrate the use of the DPF in problem framing, five design problems were developed. Two contexts for the problems were adapted from published sources related to engineering education research, one context was adapted from an authentic industry design problem, and two additional contexts were created for this research project:

- (1) **Belongings** – *Public place belongings securer* (newly created);
- (2) **Snow** – *Low-skill snow transporter* (adapted from research);^{46,47}
- (3) **Lids** – *One-hand opener for lidded food containers* (adapted from research);⁴⁸
- (4) **Rainwater** – *Remote village rainwater catcher* (adapted from industry);² and
- (5) **Supplies** – *Heavy school supplies carrier* (newly created).

The five contexts represented a diverse set in terms of the physical mechanisms involved and the surrounding details. We used the *Belongings* problem as the primary example for this paper, but we have included the adaptively and innovatively framed problem statements for the other four problems in Appendix A, for reference.

Neutrally Framed	
Context	<i>Public Place Belongings Securer</i>
	Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.
	Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space.
Need	
Goals	Develop solutions for this problem. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Figure 4. Neutrally framed version of the **Belongings** problem.

Three versions of each problem context were developed using the DPF: (a) neutrally framed, (b) adaptively framed and (c) innovatively framed. As described above, the neutral framing was intended to allow the participant to pursue the ideas they felt were best based on their preferred cognitive approach. The two non-neutral framings were intended to encourage individuals to generate either more adaptive or more innovative ideas, respectively. We start by using the DPF to develop the neutrally framed problem statement. Figure 4 shows the neutrally framed version of the *Belongings* problem. The three design problem components from the DPF correspond to three different paragraphs in the problem statement.

Public Place Belongings Securer

Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.

Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space. **Your solutions should focus on improving existing designs or adapting familiar ways of approaching the problem or similar problems.** Consider constraints such as weight and size in your solutions, so users could carry it with them. Also think about how the solution would allow someone to secure several things of various sizes at one time.

Develop solutions for this problem. Focus on developing **practical** solutions. Try to develop solutions that are cost-effective and immediately workable. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Public Place Belongings Securer

Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.

Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space. **Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem.** Don't be concerned about a particular size or weight of your solution, and feel free to choose any materials you desire, as those sorts of constraints might be able to be worked out in the future.

Develop solutions for this problem. **Focus on developing radical solutions.** Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Once the neutrally framed problem statement has been developed, we modify the statement to be adaptively and innovatively framed. Figure 5 compares the two non-neutrally framed problem statements for the *Belongings* problem. Comparing Figure 5 to Figure 4, none of the text from the neutrally framed problem statement was deleted. Instead, text was added to encourage the designers to consider more adaptive or more innovative ideas, respectively. The text in bold are general statements or words that are proposed to stimulate more adaptive or more innovative thinking. In addition to the bolded text, further clarifying statements were added to expand on the constraints and criteria important to consider for this particular problem context. When used in our studies, the bold text was included exactly as shown in Figure 5. However, the highlighting (the text with the grey background) is only used for illustrative purposes for this paper and so was not present when using the problem statements in our studies.

Exploratory Pilot Study

We conducted an initial exploration of the DPF in a pilot study. Our focus for this paper is to describe the development of the DPF and the theoretical framework on which it is based. Our future studies will include more rigorous empirical testing of the validity of the DPF. However, we conducted this initial exploratory pilot study to characterize the features of ideas students generated when they were prompted by the differently framed versions of the problems. This pilot study was not intended to serve as the final piece of evidence for testing the DPF, but rather, as a proof of concept that the DPF has the potential to structure design problems that influence idea generation in the ways we intended. Again, to maintain the focus for this paper on the development of the DPF, we report only on the *Belongings* problem context here as a representative example.

Approach

The data were collected at a large Midwestern university. A total of fifteen undergraduate students from a summer research experience program in engineering were recruited to participate in the full pilot study. The students came from a variety of universities and backgrounds. The participants ranged from having completed one to three years of undergraduate education. The choice to use undergraduates was appropriate because our interest in developing and applying the DPF is to enhance the ideation practices of engineers from a range of experience levels. Our future work with the DPF will include participants at the high school, undergraduate, graduate, and professional level, so that we may examine differences in ideation related to levels of experience and expertise.

Because we tested all five problem contexts in the full pilot study, there was sufficient time for each participant to generate ideas for only two of the problem contexts. As a result, five of the participants generated ideas for the *Belongings* problem. Of those five participants, two generated ideas for the neutrally framed version of the problem, one for the adaptively framed version, and two for the innovatively framed version. For each of the three framed versions of the *Belongings* problem, we then selected one participant to present as part of this initial exploration. In both the neutral and innovatively framed cases there was a choice about which participant to select, so we chose to include the participant who generated a greater number of ideas in order to illustrate better the range of possible ideas.

The written description of the *Belongings* problems was presented on a single sheet of paper to each participant. Each participant was also given a stack of blank paper for sketching and explaining their ideas. Participants were instructed to put only one idea on each sheet of paper and were given twenty minutes to generate ideas. They were given neither a specific nor general quantity goal in terms of the ideal number of ideas to generate. As explained above, giving participants a quantity goal may influence them to use particular sorts of ideation behaviors that deviate from their preferred or natural approach. Instead, these participants were encouraged simply to keep generating ideas for the whole twenty minutes.

It is possible to assess an individual's natural problem solving preferences on the adaption-innovation continuum using the Kirton Adaption-Innovation inventory (KAI).^{6,27} We intend to use the KAI in our future studies to test whether KAI scores predict the types and range of ideas

individuals generate, as well as how individuals with different KAI scores respond to different problem framings.⁴ However, we did not administer the KAI in our initial pilot tests of the problems developed using the DPF, and so we were not able to assess participants' natural preferences in this particular study.

As we present the example ideas below, we attempt to categorize them in ways that are central to the DPF. One way for categorizing ideas includes the extent to which each idea builds on existing solutions or ways of thinking about a problem or whether the idea approaches the problem in an entirely different way. We also consider whether an idea is more or less immediately implementable. In our future work, we intend to make these categories more formally defined with criteria that multiple coders can apply reliably. However, for the purposes of this initial exploratory pilot study, we use a more informal categorization that is suggestive of ways we may code ideas in our future work. The ideas these three participants generated serve as an illustrative example of the types of ideas that each framing may elicit and thus serve as an initial exploration of the potential impact of the DPF.

Examples

What are some ideas that are generated from a neutrally framed problem statement?

Participant A completed the ideation session with the neutrally framed version of the *Belongings* problem. This participant generated five ideas, which are numbered in the order in which the participant generated them (Figure 6). This participant generated a fairly wide range of ideas, including more adaptive ideas (A1, A3, A2) and more innovative ideas (A5). Both ideas A1 and A3 were more immediately workable and were variants of typical, existing solutions for securing belongings. Idea A2 was a platform that lowers with the touch of a button. Although implementing this idea effectively may not be simple, the solution was built on existing solutions, and it adapted common elements of desks, such as drawers that can be locked. Participant A also generated the buddy system idea (A4). Although this idea is on the more immediately workable side of the range of ideas, the solution seemed to move beyond the implicit constraints of the problem that suggested participants should develop only tangible products.

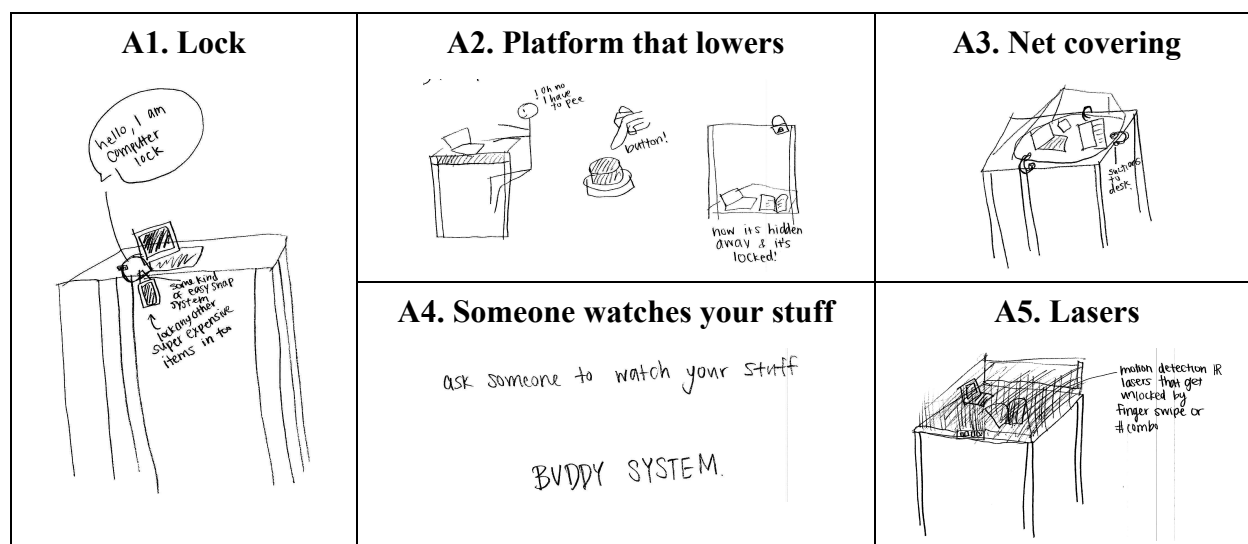


Figure 6. Ideas generated by Participant A with the neutrally framed *Belongings* problem.

What are some ideas that are generated from an adaptively framed problem statement?

Participant B was assigned the adaptively framed version of the *Belongings* problem. This participant generated only one idea (Figure 7). The idea that Participant B generated could be considered adaptive in the sense that the compartment built into a table was on the more immediately workable side of the range of ideas generated by Participant A, similar to idea A2.

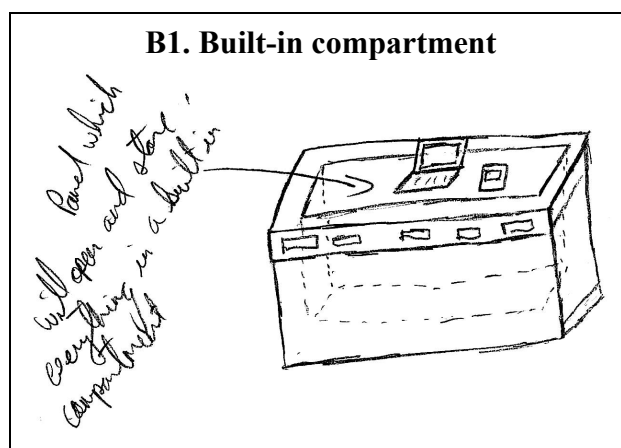


Figure 7. Ideas generated by Participant B with the adaptively framed *Belongings* problem.

What are some ideas that are generated from an innovatively framed problem statement?

Participant C was assigned the innovatively framed version of the *Belongings* problem. This participant generated four ideas (Figure 8). Similar to Participant A, Participant C generated a range of ideas, from those that were more immediately workable (C3, C1) to those that were less immediately workable (C4, C2). The more immediately workable ideas are characteristic of

more adaptive ideas, while the less immediately workable ideas are characteristic of more innovative ideas.

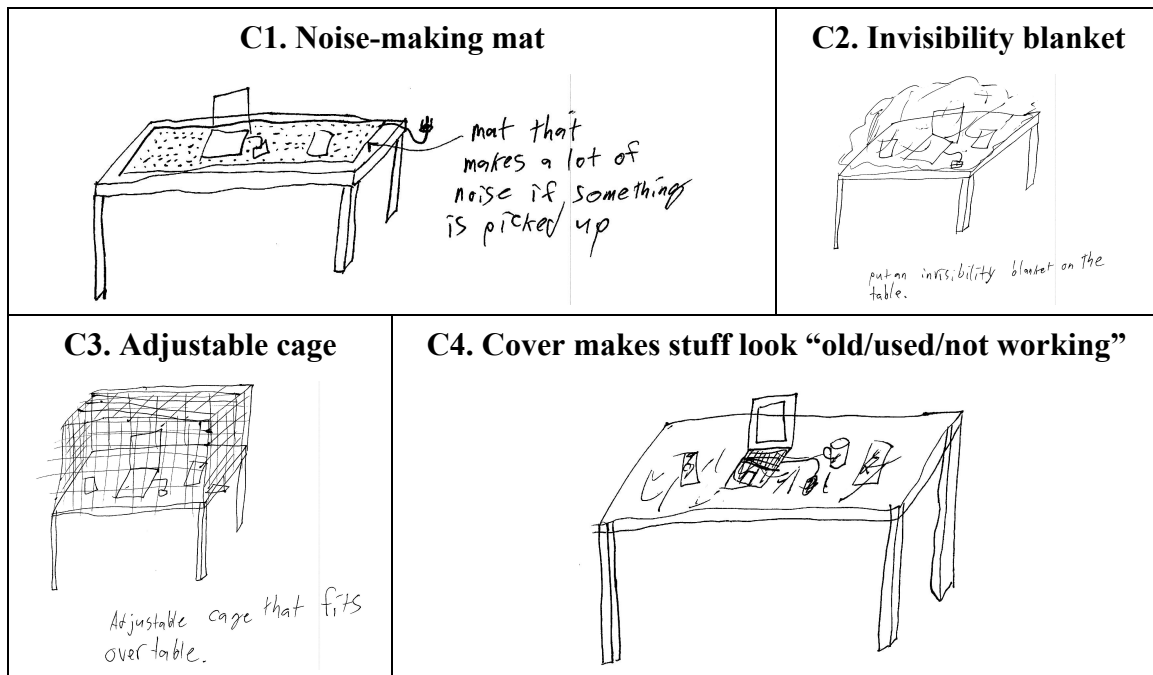


Figure 8. Ideas generated by Participant C with the innovatively framed Belongings problem.

Discussion

The results of the exploratory pilot study were promising relative to our goals for the DPF. The range of ideas generated by Participant A for the neutrally framed problem was consistent with our predictions for the DPF, because the intent of the neutrally framed versions was not to encourage participants to generate ideas of one particular type. Rather, the neutrally framed versions were constructed to be more open, so that participants could generate whichever kinds of ideas they naturally preferred or that they thought were the most appropriate for the given problem. As stated above, we did not administer the KAI in this study, and so we cannot make any claims about Participant A's natural problem solving preferences. Nevertheless, because Participant A did generate such a wide range of ideas, this example offers some preliminary evidence that the neutrally framed problem did not limit the ideas Participant A felt were appropriate for the problem to only one particular type (adaptive or innovative).

Since Participant B generated just one idea, it limits how much we could observe the range of ideas that an adaptively framed problem may elicit. It was possible that the additional constraints and criteria that were present in the adaptively framed problem limited the number of ideas Participant B considered to be appropriate, but we cannot be sure with these limited data. However, both the type of idea and number of ideas Participant B generated were consistent with our predictions for the DPF, because the intent of the adaptively framed versions was to limit participants so that they focused on generating ideas that were more immediately workable and that built on existing solutions.

Finally, the fact that Participant C felt it was appropriate to generate an idea such as an invisibility blanket (C2) for this innovatively framed problem was consistent with our predictions for the DPF. The intent of the innovatively framed versions was to encourage participants to generate ideas that were not constrained by practical concerns. Although the cage idea (C3) and the noise-making mat (C1) seem more adaptive in comparison, both are still a significant departure from common existing solutions (e.g., computer lock or locked cabinet). And, as mentioned above, more innovative idea generation may include a combination of more adaptive ideas and more innovative ideas, since a more innovative approach may consider the boundaries separating these two types of ideas to be less important. Overall, it seems that the innovatively framed version was effective in encouraging this participant to consider some innovative ideas to solve this problem.

The analysis of these examples is limited, because we reported on only three individuals and did not measure their natural ideation approaches directly. In our future studies using the DPF, we plan to include a greater number of participants at different education levels, and to measure their cognitive style using the KAI. The exploratory pilot study was also limited because we did not directly assess participants' familiarity with a problem context or with ideation generally. Familiarity with a problem context may impact the ideas a designer generates, either opening them up to exploring different possibilities, or possibly causing them to fixate on known solutions. In our future work, we also intend to assess participants' familiarity with a context using reflection surveys in which they can indicate their experience level with a particular context, as well as the solution ideas that they were aware of and that may have influenced their ideation process. Despite these limitations, the results for all three examples that we did observe were consistent with our expectations about how the different problem framings may encourage individuals to pursue one ideation approach or to use their naturally preferred approach. And thus, they serve as an encouraging first step in validating the DPF.

Conclusion

The DPF provides a structure in which to manipulate problem statements so that they encourage designers to use a more adaptive ideation approach, a more innovative ideation approach, or the approach the individual more naturally prefers. We have described the DPF and how it was used to develop five problem statements, along with the three different framings for each problem statement. Finally, we provided illustrative examples from our pilot work for how those framed problem statements could potentially enable and limit the types of ideas that an individual generates.

Our future work will further test whether the DPF problem statements are effective at encouraging different ideation approaches and outcomes. If they are effective, then the DPF could be a valuable resource for helping engineering educators to more intentionally structure their design problem statements based on their instructional goals. For example, some instructors may be unintentionally adding unnecessary constraints or criteria to their design problem statements, when they actually want their students to generate a wide range of ideas. Those instructors may be able to use the DPF to develop neutrally framed problem statements, which may then make it more likely they would observe a wider range of ideation approaches and outcomes. The instructors may then recognize the positive contributions of some students who may have had more difficulty applying their natural ideation approach otherwise. In other cases,

instructors may want to limit the students to generating either more adaptive or more innovative ideas, such as when there are real time, cost, and material constraints, and the instructors still want the students to be able to build functioning prototypes of their design ideas within the span of the course. Those instructors may be served by using the DPF to frame their design problem more adaptively. In still other cases, instructors may be able make use of the DPF to develop a set of problem statements or versions of those statements that they can assign to different groups within their course. The instructors may want to match the different framings to students' preferred approaches, or may want to get each student to try an approach different than their preferred approach. There may be a whole range of uses for the DPF in engineering education settings that encourage designers to ideate across a broader spectrum of ideas.

Acknowledgements

This research was supported by the National Science Foundation, Research in Engineering Education (REE) Grants #1264715, #1265018, and #1264551.

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Appendix A – The Design Problems

Four of the five design problem contexts developed using the DPF are presented below. The fifth design problem context—the *Belongings* problem—is presented in the main text. Each context is presented in two different versions: the adaptively framed version and the innovatively framed version. The neutrally framed version for each context can be obtained by removing the additional (highlighted) sentences in the Need and Goals sections that are included for the respective framing (see the description of the *Belongings* problem in the main text).

Snow – Low-skill snow transporter (adapted from Chusilp and Jin^{46,47})

Adaptively Framed		Innovatively Framed
<p data-bbox="297 674 600 705"><i>Low-Skill Snow Transporter</i></p> <p data-bbox="207 743 682 1077">Today skis and snowboards are widely used as personal transportation tools on snow. But to be able to use them, a lot of skill and experience are required that a user cannot normally learn within one day. Moreover, skis and snowboards cannot run uphill easily. It would be better if there were other options of personal tools for transportation on snow, which still allowed the user to control direction and braking, but did not require much time to learn how to use.</p> <p data-bbox="207 1117 682 1541">Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow. Your solutions should focus on improving existing designs or adapting familiar ways of approaching the problem or similar problems. Consider constraints such as weight and size in your solutions, so users could carry it and be able to bring it with them in their car. Also think about how the solution is powered given that it should make it easier for people to go up hill as well as downhill, but should also be reasonably affordable.</p> <p data-bbox="207 1581 682 1822">Develop solutions for this problem. Focus on developing practical solutions. Try to develop solutions that are cost-effective and immediately workable. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.</p>	<p data-bbox="756 825 865 856">Context</p> <p data-bbox="756 877 865 993">Same as neutrally-framed version</p> <p data-bbox="776 1260 846 1291">Need</p> <p data-bbox="748 1312 873 1396">Added criteria and constraints</p> <p data-bbox="773 1617 850 1648">Goals</p> <p data-bbox="743 1669 878 1785">Explicit about type of ideas most valued</p>	<p data-bbox="1019 674 1323 705"><i>Low-Skill Snow Transporter</i></p> <p data-bbox="930 743 1404 1077">Today skis and snowboards are widely used as personal transportation tools on snow. But to be able to use them, a lot of skill and experience are required that a user cannot normally learn within one day. Moreover, skis and snowboards cannot run uphill easily. It would be better if there were other options of personal tools for transportation on snow, which still allowed the user to control direction and braking, but did not require much time to learn how to use.</p> <p data-bbox="930 1117 1404 1451">Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow. Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem. Don't be concerned about a particular size or weight of your solution, and feel free to choose any materials you desire, as those sorts of constraints might be able to be worked out in the future.</p> <p data-bbox="930 1581 1404 1822">Develop solutions for this problem. Focus on developing radical solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.</p>

Adaptively Framed

One-Hand Opener for Lidded Food Containers

The local rehabilitation center helps to treat thousands of stroke patients each year. Many individuals who have had a stroke are unable to perform bilateral tasks, meaning they have limited or no use of one upper extremity (arm/shoulder). A common issue the hospital has observed with their stroke patients is in their ability to open jars and other lidded food containers. The ability to open lidded food containers is particularly important for patients who are living on their own, in which case they often don't have help around for even basic tasks. A solution to helping them open lidded food containers with one hand would go along way in helping the patients to maintain their independence.

Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand. **Your solutions should focus on improving existing designs or adapting familiar ways of approaching the problem or similar problems.** Consider constraints such as cost and size in your solutions, since patients are often on very tight budgets and generally want items that aren't going to take up much space in their kitchens. Also think about how the solution is powered, since the solution should be able to work manually rather than using electricity, which costs money and is not always reliable.

Develop solutions for this problem. Focus on developing **practical** solutions. Try to develop solutions that are cost-effective and immediately workable. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Context

Same as neutrally-framed version

Need

Added criteria and constraints

Goals

Explicit about type of ideas most valued

Innovatively Framed

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Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand. **Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem.** Don't be concerned about a particular cost or size of your solution, and feel free to choose any sort of power source that you desire, as those sorts of constraints might be able to be worked out in the future.

Develop solutions for this problem. Focus on developing **radical** solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Rainwater – Remote village rainwater catcher (adapted from Spradlin²)

Adaptively Framed

Remote Village Rainwater Catcher

In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.

Design a way for remote villagers to catch, store, and access rainwater. **Your solutions should focus on improving existing designs or adapting familiar ways of approaching the problem or similar problems.** Consider constraints such as cost and capacity in your solutions, since the remote villagers need to be able to afford the solution and to capture enough water to satisfy their needs even when there are many days between rains. Also think about the materials used in the solution since it should be easy for the villagers to construct and repair the solution as needed.

Develop solutions for this problem. Focus on developing **practical** solutions. Try to develop solutions that are cost-effective and immediately workable. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

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Design a way for remote villagers to catch and use rainwater. **Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem.** Don't be concerned about a particular cost or size of your solution, and feel free to choose any materials you desire, as those sorts of constraints might be able to be worked out in the future.

Develop solutions for this problem. Focus on developing **radical** solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Supplies – Heavy school supplies carrier (newly created)

Adaptively Framed

Heavy School Supplies Carrier

Students are increasingly being expected to carry laptops, tablets, or other electronic devices to class in addition to books, notebooks, and writing instruments. The weight of backpacks is becoming increasingly problematic, especially when students must travel across a large campus to get to class and must pack for multiple classes.

Design a way for college to carry their heavy school supplies. **Your solutions should focus on improving existing designs or familiar ways of approaching the problem.** Consider constraints such as capacity and size in your solutions, so the students would be able carry a lot of supplies with them but still be able to move in and around typical buildings and classrooms. Also think about how the student moves the carrier, since it should be straightforward for a typical college student to be able to get it to work.

Develop solutions for this problem. Focus on developing **practical** solutions. Try to develop solutions that are cost-effective and immediately workable. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

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Design a way for college to carry their heavy school supplies. **Your solutions should focus on creating totally new designs or totally new ways of approaching the problem.** Don't be concerned about a particular capacity or size of your solution, and feel free to choose any sort of carrying method that you desire, as those sorts of constraints might be able to be worked out in the future.

Develop solutions for this problem. Focus on developing **radical** solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.