Need-solution pair recognition by household sector individuals: Evidence, and a cognitive mechanism explanation

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ABSTRACT

Problem-solving by everyday individuals is thought to occur as a two-step process. First, an individual identifies or formulates a problem, followed by entering into a subsequent search to find the best solution. Here, however, we consider an alternative process that everyday individuals may use for solution finding first theorized by von Hippel and von Krogh (2016). Specifically, von Hippel and von Krogh proposed that everyday individuals may sometimes discover a solution and the need it satisfies simultaneously without the need for apriori problem formation, a cognitive process they called "need-solution pair recognition". Utilizing a rich literature from psychology and neuroscience, we propose that seemingly spontaneous discoveries found by need-solution pair recognition are natural products of the object recognition system and its underlying mechanisms. This view asserts that on encountering an object and reasoning how it might be used (i.e. functional object understanding), an individual's perception of an object may culminate in recognizing the object as a solution, and in some cases, as a solution to a problem previously unknown to him or her, thus bypassing formal problem-formulation and active solution searching entirely. To empirically test this view, we manipulated the ability of everyday individuals to functionally reason about objects while we examined the spontaneous occurrence of solutions found by either need-solution pair recognition or traditional problem-first problem-solving. Consistent with our hypothesized mechanism, our results indicate that need-solution pair recognition occurs more frequently when constraints on functional object understanding are reduced. That is, we found that needsolution pair discoveries outpaced solutions found from traditional problem solving, in environments with unfamiliar objects, where participants were not directed to solve specific problems. Our results provide clear evidence that everyday individuals in the household sector do not always innovate through traditional problem-solving processes, but instead may arrive at solutions as they recognize and reason about objects. Implications for research and practice in household innovation, and for innovation more generally are considered.

1. Introduction and overview

When considering how an everyday individual arrives at solutions, there is an assumption that a two-step process is utilized (Newell and Simon, 1972). First an individual must discover or formulate a problem, followed by the application of some search method or methods to discover or develop a satisfactory solution (Sternberg et al., 2014). Here, we term this well-known sequence the traditional need-first problem-solving pattern. Recently, von Hippel and von Krogh (2016) argued that finding solutions using only this need-first problem-solving sequence may be especially impractical for everyday individuals. Illustrating with examples, they explained that, under common, real-world conditions, discovery or formulation of the "right" problem in advance of solution development could be very difficult or impossible. Accordingly, they hypothesized that a second and quite different way in which solutions may be discovered or recognized may exist. Specifically, they proposed that everyday individuals may often identify both solutions and the problems they address in a joint manner - *without* a prior problem-formulation step. They termed this process need-solution pair recognition.

A well-known example of a famous discovery made through need-solution pair recognition is Velcro. Velcro was reported by its inventor,

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de Mestral, to arise from the mundane experience he had when a plant burr stuck to his clothing. In trying to understand how the burr clung to his pants, de Mestral reported recognizing both how its clinging mechanism worked, and how that mechanism could be used to make better fasteners. For de Mestral, both the problem and the solution paired with it came to his conscious mind simultaneously, and both were novel to him at the time of his discovery (Cunha et al., 2010).

The traditional view of instances such as de Mestral's discovery is that they arise from moments of "serendipity", a term referring to "accidental sagacity" – in effect, luck. Horace Walpole first devised the term serendipity in 1754 by referring to the Persian fairy tale "The Three Princes of Serendip" in which the three were "always making discoveries, by accidents and sagacity, of things which they were not in quest of…" (Walpole, 1960, pp. 407–408). As he further noted, "you must observe that no discovery of a thing that you are looking for comes under this description" (Walpole, 1960, p. 408). Such serendipitous discoveries by individuals have been viewed as a product of chance or some stochastic process (e.g., Simonton, 2003). This has left researchers and practitioners looking for an active way to inject "chaos" or "chance" in their organized practices in an effort to engineer serendipitous discoveries (Brown and Eisenhardt, 1998; Dew, 2009; Yaqub, 2018). Our view and results however run counter to these approaches and claims.

In this paper, we propose that some serendipitous discoveries may be products of an orderly perceptual-cognitive process that underlies natural object recognition. As we will explain, research has shown that to recognize an object one must reason about its purpose or function (Barsalou, 1999; Chemero, 2009; Glenberg, 1997). It is our view that this process may result in solution-finding when the object (in part or whole) is understood as a solution to a previously unidentified problem. In this way, the recognition system provides a forum where both elements of a novel need and novel solution may be brought to mind simultaneously, allowing the viewer to completely circumvent a priori problem formulation and time-consuming searches for solutions. In the view we develop here, while the encounter leading to the recognition of a serendipitous need-solution pair may perhaps arise by chance, the insight process underlying its inception is not random at all, but instead reflective of an organized process within the mind of the individual.

As we will report in detail later, the outcome of our experiment is consistent with the view that discoveries by need-solution pair recognition stem from the functional understanding of objects. Specifically, in our experiment we found that factors that are known to decrease the functional recognition of objects, led to a decrease in the occurrence of discoveries by need-solution pairs. Our ability to control the occurrence of need-solution pair recognition by manipulating functional object understanding suggests that need-solution pair recognition is reflective of an orderly cognitive process rooted in object recognition. Based on this observation, we will argue that need-solution pair solution finding should be thought of not as unpredictable luck, but rather as a cognitive process, and as such trainable through experience. We should note that, while our experiment focused on physical objects, we hold that our results will generalize to other kinds of objects such as processes or algorithms.

Both our experimental study and research on user innovation focus on innovation in everyday life situations conducted by individuals, not researchers or R&D staff (Gambarella et al., 2016; von Hippel, 2017). As such, our study offers a variety of implications for user innovation research in general and research on household sector innovation specifically. The results of the study offer empirical evidence that challenges the notion that everyday individuals in the household sector only find solutions through traditional problem-solving processes (see for example Keinz et al., 2012). Instead our results indicate that everyday individuals in a domestic setting can arrive at solutions as they reason and recognize objects in their environment. In the discussion section we offer consideration for how this shift in understanding may influence future work on innovation in the household sector, and innovation

research more broadly. We hold that improved understanding of the phenomenon of need-solution pair recognition will be particularly useful to householders and others in similar situations. First, it is a cognitive phenomenon that naturally occurs in the minds of everyday individuals. Second, when it does occur, it is subjectively costless: a matter of clear importance to resource-constrained householders. Third, as we will explain, householders will often be in a position to benefit from a greater fraction of need-solution pairs that spontaneously come to mind than are firms, making this form of "problem-solving" especially valuable for them.

In the sections that follow, we first summarize extant literature on cognitive psychology, neuroscience and philosophy to serve as the basis of our argumentation (Section 2). Next, we draw specifically on this literature to offer the general hypothesis that need-solution pair discoveries arise from the functional understanding of objects (Section 3). Then, we present our research methods (Section 4) and our findings (Section 5). In Section 6 we discuss our findings and their importance, and then conclude with a discussion of both theoretical and practical implications.

2. Literature review

In this section, and also in Section 3, we elaborate upon existing theoretical contributions from cognitive psychology, neuroscience, and philosophy to clarify the neurobiological plausibility of need-solution pair recognition occurring in the minds of everyday individuals.

2.1. The recognition of objects is granted through functional object understanding

In 1977, Gibson coined the term "affordances" to refer to the set of potential uses or functions a given object or set of objects may offer or "afford". For Gibson, the affordances of a given object represent an invariant mapping from the features and form of that object to its meaning, suggesting that affordances themselves are the object of perception. Indeed, simple introspection reveals that individuals seem to be able to perceive the functions of objects just as readily as their simple physical features (Gibson, 1979, 1977).

While Gibson's theory of affordances made powerful claims regarding the import of functional object understanding in shaping and constraining object recognition, it offered little insight as to how the detection and perception of affordances occurs. Enactive and embodied theories of perception however, have extended Gibson's theories by positing that affordances are perceived through the sensorimotor systems in the brain (Barsalou, 1999; Chemero, 2009; Glenberg, 1997). Under such a view, when one looks at an object, one recognizes it via its potential uses or functions by internal simulations of potential motor actions afforded by the object. Such a view is supported by converging evidence across a wide range of studies showing that the recognition of an object entails the contemporaneous activation of sensorimotor areas that capture the potential uses and functions of the given object along with other representations such as the given object's visual image and sound (Allport, 1987; Anderson et al., 2002; Damasio, 1989; Lissauer and Jackson, 1988; Rogers et al., 2004; Saffran and Schwartz, 1994; Simmons and Barsalou, 2003; Warrington and Shallice, 1984). For example, an individual may recognize a pencil holder as potentially serving the function of a cup if it can be picked up and hold liquid.

Enactive and embodied theories of perception have also extended Gibson's original term of affordances to acknowledge the dynamic interdependence that exists between an observer's intentions and the affordances of an environment (Chemero, 2009; Noë, 2004; Thompson, 2007; Varela et al., 1993). This expanded view of affordances has been corroborated by neuropsychological evidence from humans and macaque monkeys demonstrating that object recognition may be best described by two neural pathways, with interactions

between the pathways capturing the dynamic relationship that exists between knowledge from prior experiences (specified here as learned affordances) and action-mediated recognition from physical features (specified here as ad hoc affordances) (Milner, 2017; Milner and Goodale, 2008, 2006; Norman, 2002; Young, 2006).

2.2. Functional object understanding as a wellspring for solution-finding

While research described in the previous section suggests that object understanding is determined by both learned and ad hoc affordances, this is not to say that affordance understanding *only* serves object understanding. Affordances by their very definition (whether learned or ad hoc) represent the full set of action possibilities available to an individual (Milner, 2017; Milner and Goodale, 2008, 2006; Norman, 2002). Given that these action possibilities can be thought of as potential solution paths available to an individual, affordance understanding may have strong implications for solution finding. Indeed, complex behaviors such as problem-solving or solution finding may be best thought of as emergent properties of situated, action-oriented object understanding. Accordingly, the examination of the affordance landscape as a solution space that is independent of problem formulation offers the valuable observation that situated action-object understanding provides powerful machinery for the emergence of what von Hippel and von Krogh (2016) proposed – that is, "need-solution pairs."

Realizing that solutions may be identified from the properties of objects suggests that objects themselves harbor solutions. Once this is made clear—that not all solutions are derived from logical-form, problem-first situations—alternative approaches to innovation from insight and cognitive creativity become clear; that is, a seemingly serendipitous discovery may come from a simple glance at a novel object whose functional properties are seen immediately to solve a problem that was not previously conceived as a problem.

3. Hypotheses

If the perceptual-cognitive mechanism of object recognition indeed underlies need-solution pair discoveries, it holds that any constraints on functional object understanding should limit the occurrence of solutions by need-solution pair recognition. To manipulate functional object understanding in this study we used two different methods. First, we reasoned that overt instruction to solve a problem would reduce the likelihood of need-solution pair occurrence, as it would necessarily constrain functional object understanding to those functions that relate to the actively held problem needing to be solved (Adamson, 1952; Chrysikou, 2006; Chrysikou and Weisberg, 2005). For this reason, across participants, we varied the overt instruction to problem-solve across three experimental conditions. Second, a subject's prior familiarity with objects encountered would reduce the likelihood of need-solution pair discoveries, as prior familiarity with objects is known to constrain functional object understanding to previously encountered affordances of those objects (Chrysikou and Weisberg, 2005; Duncker, 1945). For this reason, in our experiment participants were exposed to two sets of objects that differed in visual novelty. That is, how novel the trigger object looked, and how novel the trigger object was in terms of its possible function.

3.1. Overt instructions to problem-solve and its influence on affordance perception

We hypothesize that, if an experimental subject is given instructions to solve a specific problem, that this will reduce the occurrence of need-solution pairs relative to a situation where no such instructions are given. We reason that attention towards a specified problem will

necessarily influence one's current goals, which will in turn affect the cognitive salience of past experiences and will also influence expectations (e.g., Adamson, 1952; Chrysikou, 2006; Chrysikou and Weisberg, 2005). The result will be to reorganize and constrain the affordance landscape to increase focus on solution paths that potentially satisfy the needs of the considered problem (see Getzel, 1975). The notion that stating a problem *can* constrain the breadth of subjects' functional object understanding hints at an important feature of object-based solution spaces: As they are not dependent on problems for their generation, such spaces may contain solution paths to problems not yet known or considered. Indeed, it is via such paths that we argue that need-solution pair recognition arises. Therefore, any instructions that direct attention *away* from such paths should reduce the likelihood of need-solution pair emergence.

Given our view on how actively held problems necessarily constrain affordance understanding we propose the following:

Hypothesis 1a. (H1a). *As active engagement in problem-oriented solution finding is decreased, need-solution pair identification will increase.*

As previous research has already demonstrated, as a problem-statement becomes more defined, need-first solution-finding for that problem increases (e.g., Schraw et al., 1995), we further propose that:

Hypothesis 1b. (H1b). *As active engagement in problem-oriented (need-first) solution finding is decreased, traditional problem-first solutions will decrease.*

3.2. Perceived object novelty and its influence on affordance perception

As we have previously discussed, the affordance landscape for a given perceiver is defined through an interplay between observable affordances and those learned via past experience. This interplay becomes clear when considering how affordance processing for a given object may change with experience. Previous research has shown that once a particular usage for an object is reinforced, participants are much less able to use the object in a novel way for the purpose of subsequent problem-solving (Adamson, 1952; Birch and Rabinowitz, 1951; Duncker, 1945). For example, participants will fail to see that they can use a hammer as a counterweight to make a pendulum in order to solve a problem, as the affordance they ascribed to a hammer is limited to its canonical usage: to drive nails. This notion, that an individual is unlikely to deviate from the previously learned affordance of an object, has been referred to as "functional fixedness" (Chrysikou and Weisberg, 2005; Duncker, 1945). Findings related to functional fixedness are quite robust and have been broadened over time beyond physical objects to show the effect is very general. Thus, it has been demonstrated that participants familiar with a complicated problem-solving strategy are unlikely to devise a simpler one even when appropriate (Allen and Marquis, 1964; Luchins, 1942).

In the context of our research, we hold that objects can be thought of as existing on a continuum from novel to familiar, with the experience an individual has with an object dictating where the object falls on that continuum. Put simply, familiar objects are familiar due to prior experience, and novel objects are novel due to a lack of prior experience. Given (1) our view that need-solution pairs are born out of our recognition system and (2) that visual processing is highly sensitive to the novelty of objects, as specified through prior experience (Schomaker and Meeter, 2012), we chose to use ratings of visual object novelty as a proxy for overall object novelty. As mentioned, previous literature on functional fixedness has documented that affordance processing of familiar objects is constrained or biased towards familiar uses and affordances (in contrast to novel objects). Therefore, it is reasonable that the full breadth of affordances an object may offer will be more likely to be discovered by participants if they are presented with objects that are unfamiliar or novel to them. Given our view that

constraints to the affordance landscape will hinder need-solution pair recognition, we propose the following:

Hypothesis 2a. (H2a). *Need-solution pair recognition will occur more when participants interact with objects that are judged to be more novel than when interacting with objects that are judged to be more familiar.*

The same argumentation holds for the quality of those discoveries, specifically their novelty. Functional fixedness is likely to point a participant's perception of possible object uses towards familiar uses when objects are already well known to the participant and prevent the subject from recognizing need-solution pairs, thus:

Hypothesis 2b. (H2b). *Objects that are judged to be more novel will trigger more novel solutions via need-solution pair recognition than objects that are judged to be more familiar.*

As previous research has already demonstrated that a functional fixedness (created through familiarity) negatively impacts traditional solution-finding (Duncker, 1945), we further propose that:

Hypothesis 2c. (H2c). *Traditional need-first problem-solving will occur more when participants interact with objects that are judged to be more novel than when interacting with objects that are judged to be more familiar.*

3.3. Creativity and affordance perception

In addition to the two main hypotheses, we also hold that there will be a difference in perceived creativity between solutions generated by need-solution pair recognition and those obtained through traditional need-first solution-finding. Our logic stems from the notion that objects that are familiar to given individuals are often understood through their canonical usage – recall from above that this phenomenon is referred to as functional fixedness. Functional fixedness has been shown to inhibit a process called analogical reasoning (Christensen and Schunn, 2007). There is a growing consensus among cognitive psychologists that analogical reasoning is a key cognitive process important to creativity (Barnett and Ceci, 2002; Bowdle and Gentner, 2005; Green et al., 2008; Holyoak and Thagard, 1995; Mayer, 1999; Sternberg, 1977). Broadly, analogical reasoning is the process by which individuals make sense of a novel situation or object by comparing it to more familiar situations or objects. In terms of affordance processing, analogical reasoning may be an important mechanism by which perceivers are able to transfer learned affordances from past objects to new objects (Chaigneau et al., 2009). Previous research on analogical reasoning has demonstrated that analogies that bridge large semantic distances are generally perceived as more creative than those that bridge small distances (Dunbar and Blanchette, 2001; Holyoak and Thagard, 1995; Sternberg, 1977). For example, the semantic distance between dog and cat is relatively small, while the semantic distance between dog and rug is relatively large. Further, as distant analogies allow for novel comparisons that can reveal aspects not yet considered, (e.g., "That a dog is lazy as a rug – it just lies there"), semantically distant analogies may be much more valuable than semantically close analogies (Dunbar and Blanchette, 2001; Holyoak and Thagard, 1995; Sternberg, 1977). In particular, objects novel to perceivers are likely to offer those individuals comparatively more opportunities relative to familiar objects to demonstrate generativity and creativity, as novel objects not encumbered by previously learned affordances can inhibit analogical reasoning and thus creativity (Christensen and Schunn, 2007). We therefore posit that encounters with novel objects will not only result in an increase in the production of solutions via need-solution pair recognition, but that such interactions will provide better opportunities for creativity and generativity, given the unfettered nature of functional object understanding thought to mediate such discoveries. We therefore propose the following:

Hypothesis 3. (H3). *Solutions recognized as an output of need-solution pair recognition will have higher perceived novelty and creativity than solutions found via traditional need-first problem solving.*

4. Research methods

4.1. Participants

Seventy-four participants were recruited from the local community surrounding Technische Universität Darmstadt (63.5% = male, 36.5% = female; M = 25 years, range: 13 years to 59 years; 60 undergraduate students, 14 non-students). Informed written consent for all participants was obtained prior to the experiment in accordance with the guidelines established by the German Ethics Council applied by the ethics council of Technische Universität Darmstadt. All participants received financial remuneration of 10€ for completing the study, and additionally had the chance to win an Amazon voucher of 100€. Given the expected effect sizes and methods used to test our hypotheses, a total of 74 participants was considered an appropriate sample size (G*Power 3.1.92 software, see Faul et al., 2007).

4.2. Experimental setting

The experimental procedure was carried out in a research lab at Technische Universität Darmstadt. The experiment took place in a room that was made to resemble a domestic "Airbnb" environment intended to be rented to guests for overnight stays (See Fig. 1, Panel A). This environment allowed us to surround participants with familiar and everyday objects within a contextual background familiar to household sector participants, while they were not actually in their own home. During a pre-session briefing, all participants received a general description of Airbnb and how it works to provide a similar contextual background across all participants (Aguinis and Bradley, 2014). In addition to typical items found in an Airbnb rental, the room also contained a closed opaque cabinet filled with visually novel objects (See Fig. 1, Panel B), which participants were only invited to open at the midpoint of their individual experimental session. A separate room, with no view of the experimental setting, was used for pre- and post-session interviews with research participants.

4.3. Experimental procedure and design

On arrival, participants were randomly assigned to one of three conditions that differed only in terms of the level of overt instruction to problem-solve. In the first condition (N = 25), participants were invited to simply enter and explore the room without any explicit instruction to problem solve, here after referred to as the "NoPS" condition. In the second condition (N = 26), however participants were invited to develop an idea for something that could be useful to them or others while they explored the room, here after referred to as the "BroadPS" condition. As such, the second condition represented an invitation to explicitly problem solve at a broad level when exploring the room. In the third group (N = 23), participants were asked to think of needs and problems specific to people in an Airbnb setting and create useful solutions to those needs while exploring the room, here after referred to as the "SpecificPS" condition. Compared to the BroadPS condition, the third condition represented an invitation to explicitly problem-solve in a much more specific way. To ensure each participant understood the instructions associated with their condition, participants were asked to write down what they understood the instructions to be. In case of any issues or differences, we corrected their understanding, and asked them to again provide a written summary of the instructions to double check that they properly understood.

Before entering the Airbnb room participants were also asked to wear a wireless video and eye-tracking apparatus that looked like a pair of eyeglasses. As was explained to participants, this apparatus would continuously transmit to a remote recording device located in the interview room. It would enable the experimenters to record a continuous visual image of where participants were located in the Airbnb room at any moment, and also exactly what they were looking at. (The specific
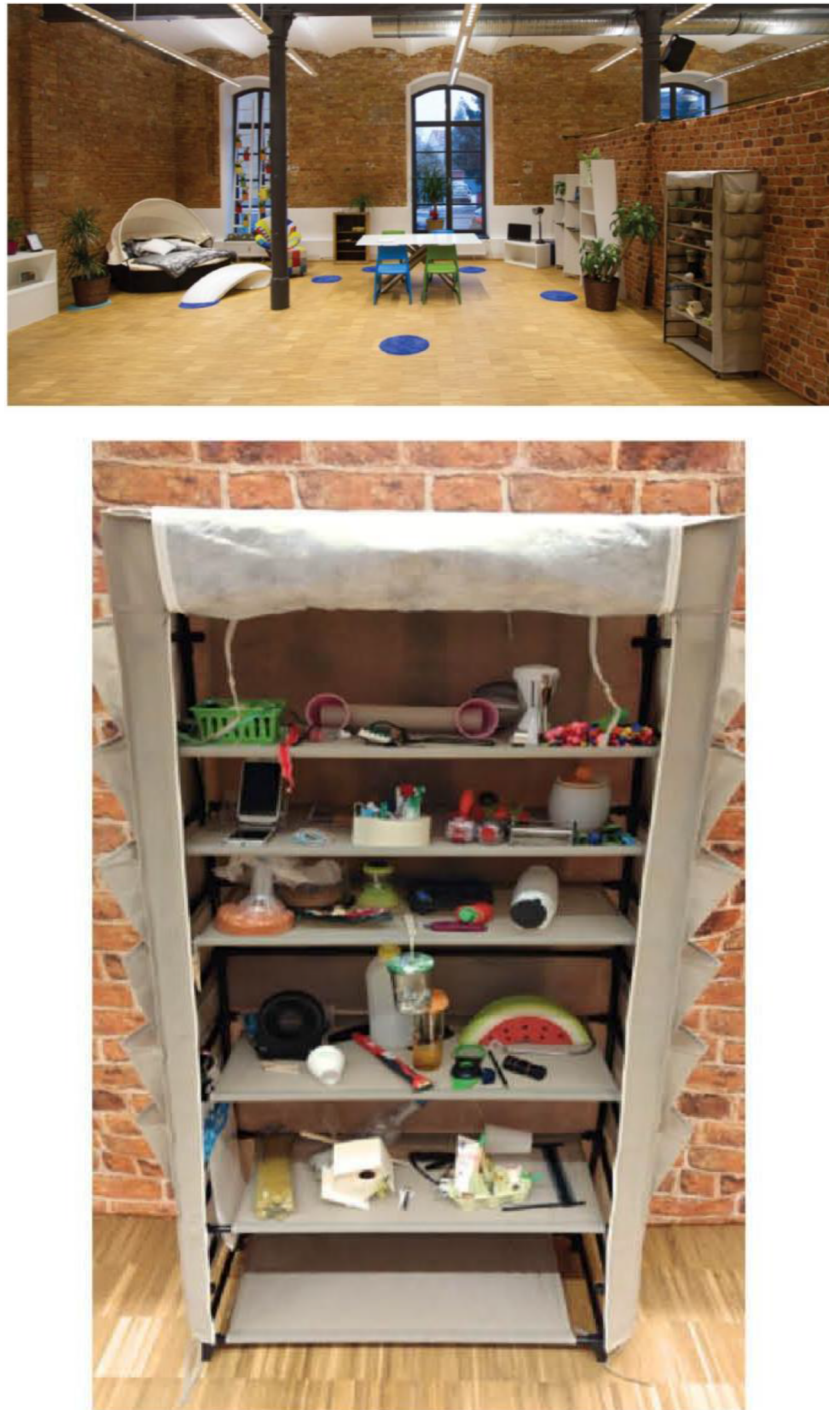
Fig. 1. Top panel shows the experimental setting at the leap in time lab in which participants were placed. Bottom panel shows the object cabinet that was filled with visually novel objects.

apparatus used was the wireless SMI Eye Tracking Glass 2.)

After instructions were made clear, each participant was invited to enter the Airbnb room that contained visually familiar objects. Participants were free to move around and handle objects or shift their locations. For all sessions, the experimental room was kept free of external sounds, and room lighting and room temperature were maintained at normal residential levels. After the first 5 min of browsing the room filled with familiar objects, participants were then given a key, and asked to open the (opaque) door to the cabinet containing the

visually novel objects. The cabinet contained an assortment of visually novel, domestic objects (See Fig. 1B, further up-close pictures of all objects - both visually novel and familiar - in the room will be made available upon request). For example, a foot-long hollow tube 1 inch in diameter had a head shaped like a bear and many small indentations for feet. This object was intended by the producer to be used to make ice cubes, by partially filling it with water and putting it into a freezer "feet down" so that many small ice cubes would then form in the indentations for the bear's feet. However, that producer-intended use was not

obvious to most participants based on visual inspection alone, as the object was visually distinct from most other ice cube trays. Participants were then invited to stay in this setting containing the visually novel objects for five more minutes, after which they were asked to leave the Airbnb setting and return to the interview room for a post-interview and debriefing. In addition, as a source of contextual and explanatory data, information on participants' personality traits and their moods during the experiment were collected. At the end of each session, the experimenters returned all objects in the room to their original positions, and re-closed the cabinet filled with visually novel stimuli.

4.4. Data collection and analysis methods

Recall that the primary purpose of this experiment was to examine whether functional object understanding supports solution-finding by need-solution pair recognition. To examine this, we manipulated whether visual object novelty and explicit instruction to solve a problem affects the occurrence of: (1) need-solution pair solution finding (occasions where both need and solution were recognized by the participant simultaneously) and; (2) traditional "need first" solution finding. To answer these questions we utilized a 2-by-3 effect design, containing both a between-subject manipulation (Task Instructions: NoPS, BroadPS, and SpecificPS) and a within-subject experimental manipulation (Visual Novelty: Low and High).

Given our interest in directly comparing the number of solutions recognized as need-solution pairs (occasions where both an unknown need and solution were recognized by the participant simultaneously) to the number of need-first problem solutions generated (occasions where a solution was found for a previously known problem) for each experimental condition, these measures were treated in tandem as a repeated dependent measure. Lastly, we verified the effectiveness of our within-subject manipulation by asking each participant during debriefing to assess the unfamiliarity, innovativeness, complexity, and their interest using a 5-point Likert scale, of the Airbnb setting both before and after the cabinet was opened. The manipulation check data, as shown in Table 1, depicts the mean differences in perception of the setting before and after the introduction of the cabinet and shows that the desired effect of the cabinet was achieved.

4.4.1. Video and eye-tracking information

Data on need-solution pair and need-first solution occurrences were collected from participants after each experimental session using the video of each participant's session, including eye-tracking information (shown as a moving dot within the video image). This footage was then played on a screen for the participant and interviewer to look at jointly. The participant was then asked to use the footage available to recall the thoughts they had while they were in the Airbnb room. Using first-person perspective videotapes to trigger participants' recall of mental events is a common approach in psychology, marketing and creativity research (Belk and Kozinets, 2005; Glăveanu and Lahlou, 2012; Lahlou et al., 2015; Rosenthal and Capper, 2006). It is thought that participants are better able to recall their thoughts while watching a

Table 1
T-test for mean differences in perception of the setting before and after our novelty-enhancement manipulation.

Perception of the setting as...[1]	Low Novelty Setting (I)	High Novelty Setting (J)	Mean Difference(I-J)	Sig.
Interesting	2.25	3.18	−0.93***	.000
Innovative	2.00	3.01	−1.01***	.000
Complex	1.10	2.30	−1.20***	.000
Unfamiliar	2.47	3.23	−0.76***	.000

[1] Measured on a 5-point Likert scale: 1 = not at all, 5 = extremely.
*** Mean difference is statistically significant at $p < 0.001$
$N = 74$.

replay of the events.

4.4.2. Coding instances of problem solving

As previously indicated, all need-solution pairs and need-first solution occurrences were noted during the video review process. In order to correctly classify solutions as need-solution pairs or need-first solutions, all solutions discussed by participants were subject to a series of questions. More specifically, when participants indicated in their narrative that they had been thinking about a need and/or a solution, the experimenter asked them: (1) whether their awareness of a problem preceded and triggered their search for a solution (an instance of the traditional need-first problem-solving) or; (2a) whether the solution occurred spontaneously along with the need it satisfied. If they said that the solution occurred spontaneously to them, they were additionally asked (2b) whether both the need and the solution in question were both previously unknown to them before their insight. Only if they also answered yes to this second question, did the experimenter then code that occurrence as an instance of need-solution pair recognition. Via this procedure, we were able to gather occurrence data for need-solution pair recognition and need-first solutions.

4.4.3. Coding novelty, creativity, and general value of solutions

As part of the debriefing process described above, we asked the participants to *describe* each need and related solution that had come to their minds during their time in the experimental setting, while we wrote down what they said. We then showed the participants what we had written, and corrected any misunderstandings (Glăveanu and Lahlou, 2012). At the end of the interview, we asked participants to rank their solutions, starting with the "most important" one.

We later asked four graduate student lab assistants to serve as third-party raters and independently assess the (1) novelty, (2) creativity, and (3) general value of each discovery based upon the short description of each that had been collected as described above ($N = 314$). The use of independent coders to assess individual outcomes such as creativity or novelty of ideas is widely accepted and established in management research and is assumed to reduce common method bias (Baer et al., 2004; Saal et al., 1980). As recommended by extant research, we adapted a two-way rating approach by asking each rater to provide a score for each measure and each idea (Baer et al., 2004; Saal et al., 1980). Initially, raters jointly reached a consensus on what each brief description meant – what the product to be rated actually was and what its intended function was. Next, they performed the rating task independently, with no consultation about the ratings throughout the whole rating process (Amabile, 1983).

Novelty was measured using a self-developed three-item construct, based on the novelty dimensions of Im and Workman's (2004) scale adapted by Stock et al. (2014). The measure was designed to cover multiple dimensions of novelty using the following items: (1) "The solution is novel," (2) "The solution is unique compared to other solutions on the market," and (3) "The solution is really out of the ordinary." Raters scored each of the items on a five-point scale ranging from (1) strongly disagree to (5) strongly agree. Overall, the ICC scores for each item show good inter-coder reliability (ICC scores were 0.78, 0.77, and 0.77 respectively). Accordingly, we averaged the scores. A Cronbach's alpha of 0.89 showed good overall construct reliability of the novelty scale, allowing us to use average construct scores in our further analyses.

Creativity was measured as a subjective degree on a 5-point Likert scale inspired by Amabile (1983). Accordingly, each rater reported the degree to which by his or her own subjective definition of creativity, the solution was (1) very uncreative – (5) very creative (ICC = 0.80). Average values on the item level were computed.

Besides being crucial measures to determine the quality of a certain discovery, neither novelty and creativity say much about the "practical" value of a discovery. For example, creating a rattle using beans and two folded egg boxes from the cabinet might be seen as an act of creativity

Table 2
Descriptive statistics related to solutions per participant for each experimental condition.

	Instruction Type	NF Solutions under High Object Novelty	NF Solutions under Low Object Novelty	NSPs under High Object Novelty	NSPs under low Object Novelty
N	NoPS	25	25	25	25
	BroadPS	26	26	26	26
	SpecificPS	23	23	23	23
Missing	NoPS	0	0	0	0
	BroadPS	0	0	0	0
	SpecificPS	0	0	0	0
Mean	NoPS	1.00	0.120	2.72	0.360
	BroadPS	1.31	0.615	1.92	0.462
	SpecificPS	1.65	1.04	1.39	0.174
Standard Deviation	NoPS	0.866	0.332	1.49	0.569
	BroadPS	1.32	0.852	1.29	0.811
	SpecificPS	1.67	1.36	1.03	0.388
Range	NoPS	3.00	1.00	5.00	2.00
	BroadPS	4.00	2.00	5.00	3.00
	SpecificPS	7.00	5.00	4.00	1.00
Minimum	NoPS	0.00	0.00	1.00	0.00
	BroadPS	0.00	0.00	0.00	0.00
	SpecificPS	0.00	0.00	0.00	0.00
Maximum	NoPS	3.00	1.00	6.00	2.00
	BroadPS	4.00	2.00	5.00	3.00
	SpecificPS	7.00	5.00	4.00	1.00

and also be novel but at the same time offer limited practical value for most people in most situations. Thus, it is important to derive a third measure that specifically covers this dimension. *General value* was assessed using a single item measure put forth by de Jong and colleagues (2015). Specifically, independent coders assessed the degree to which the solution would be valuable to other people (ICC = 0.61). Ratings were coded on a 5-point scale with respective anchors ranging from "no potential" to "great potential." Again, average values on the item level were computed.

4.4.4. Personality questionnaire data collected

In addition to post-session data collection on need-solution pair and need-first solution occurrences, questionnaire data on other matters, such as personality traits, were collected from all participants prior to the start of their 10-minute session in the room, and also immediately after their session for validation purposes. By doing this, we sought to account for the fact that, for example, people with larger openness to experience are more likely to come up with more novel solutions, and sought to insure that the proportion of highly open people was represented equally in each of the groups. The self-rated personality trait for *openness to experience* was assessed using a 4-item measure developed by Donnellan and colleagues (2006). This measure includes questions such as, "I have a vivid imagination," or when reverse coded, "I have difficulty in understanding abstract ideas." The construct was assessed on a 5-point Likert scale (1 = not at all, 5 = very much).

4.4.5. Coding visual novelty associated with each object that triggered either a need-solution pair or need-first solution

For each solution reported, we asked the participants if there was an object or groups of objects that lead to the solution (either through need-solution pair recognition or need-first strategies). We later asked four graduate-level lab assistants to serve as third-party raters and independently assess object novelty for each of the identified trigger

objects. While we were only interested in visual novelty ratings for the trigger objects, raters were also asked to rank: (1) how novel the trigger object looked and; (2) how novel the trigger object was in terms of its possible function. Each assessment was done using a 6-point Likert scale (1 = Highly Not Novel, 6 = Highly Novel). While these two items are likely related, this was done so as to make sure that raters knew to separate visual novelty from novelty associated with the object's possible function. The four rater's assessment of visual object novelty (Cronbach's alpha 0.80) and assessment of novelty for each object's possible use (Cronbach's alpha 0.80) both showed high agreement among the raters. While the two novelty assessments (visual appearance and usage) were significantly correlated ($r = 0.253$, $p = 0.04$), the percent of total variance explained by the relationship was less than 7%. Per H2b, the measure of visual novelty for each trigger object was obtained, so as to assess if high visual novelty positively predicts how often an object serves as a trigger for need-solution pair recognition.

5. Results

In our experiment, we documented many instances of both need-solution pair recognition and need-first solving processes among our participants. The occurrence of solutions per participant (the total of solutions found, either by need-solution pair recognition or by need-first strategies) during their 10-minute sessions in the experimental setting ranged between 1 and 12 solutions per participant with a mean of 4.24 and a standard deviation of 2.34. As prior literature would suggest (Stock et al., 2016), the total number of solutions generated by individual participants was significantly correlated with the degree to which each participant displayed the personality trait, openness to experience ($r = 0.268$, $p = 0.021$). For descriptive statistics of our data by experimental group, see Tables 2 and 3.

Table 3
Descriptive statistics related to ratings of general value, creativity and novelty for each solution by each experimental condition.

	Instruction Type	Object Novelty	Solution Type	General Value	Creativity	Novelty
N	NoPS	Low	Need First Solutions	3	3	3
			Need Solution Pairs	9	9	9
		High	Need First Solutions	25	25	25
			Need Solution Pairs	68	68	68
	BroadPS	Low	Need First Solutions	15	15	15
			Need Solution Pairs	12	12	12
		High	Need First Solutions	34	34	34
			Need Solution Pairs	50	50	50
	SpecificPS	Low	Need First Solutions	24	24	24
			Need Solution Pairs	4	4	4
		High	Need First Solutions	38	38	38
			Need Solution Pairs	32	32	32
Mean	NoPS	Low	Need First Solutions	3.08	1.58	1.56
			Need Solution Pairs	2.92	2.78	2.65
		High	Need First Solutions	2.90	2.37	2.05
			Need Solution Pairs	2.75	2.58	2.32
	BroadPS	Low	Need First Solutions	3.30	2.17	1.89
			Need Solution Pairs	3.02	3.19	2.60
		High	Need First Solutions	2.73	2.50	2.13
			Need Solution Pairs	2.59	2.39	2.08
	SpecificPS	Low	Need First Solutions	3.27	1.34	1.28
			Need Solution Pairs	3.31	1.94	1.56
		High	Need First Solutions	2.61	1.69	1.61
			Need Solution Pairs	2.72	2.37	2.05
Standard deviation	NoPS	Low	Need First Solutions	0.144	0.144	0.459
			Need Solution Pairs	0.673	1.230	1.070
		High	Need First Solutions	0.650	1.030	0.907
			Need Solution Pairs	0.551	0.881	0.734
	BroadPS	Low	Need First Solutions	0.649	1.190	0.954
			Need Solution Pairs	0.505	1.210	1.090
		High	Need First Solutions	0.572	1.070	0.749
			Need Solution Pairs	0.646	0.936	0.745
	SpecificPS	Low	Need First Solutions	0.817	0.603	0.449
			Need Solution Pairs	0.315	0.826	0.427
		High	Need First Solutions	0.709	0.752	0.619
			Need Solution Pairs	0.549	0.965	0.778

5.1. Solutions generated in the experimental setting

Recall that participants were asked to identify the objects or groups of objects that appeared to trigger their solutions (by either need-solution pair recognition or need-first problem-solving) in our post-session interviews. For details on this assessment process, see Section 3.4.3. In 90% of the instances, our participants were able to identify an interaction with an object in the setting that led to their solution (either found by need-solution pair recognition or need-first strategies). For example, while exploring the room, one participant said that an encounter with a tin container, shaped and colored like a traditional yellow checker taxi prompted her to think that it could be used as a game piece to play a board game – only on a much larger scale. She immediately realized that playing a board game on a large scale would allow her to be active while still playing a game with her friends – an attribute she discovered she desired. Experimentally, this was marked as a solution found by need-solution pair recognition, as the participant reported that both the solution and need were new to her, and came to her consciousness simultaneously through her encounter with the taxi-shaped container. Further examples of other need-solution pairs found by different participants as well as solutions found through need-first strategies are depicted in Appendix 1.

5.2. Effect of novelty and instruction type on the occurrence of solution by need-solution pair recognition and need-first strategies

Remember that explicit instruction to problem-solve and object novelty were both manipulated to see if factors known to affect functional object understanding influenced the occurrence of need-solution pair discovery. In order to assess the effects of both the explicit instruction to problem-solve (See Hypothesis H1a/H1b) and object novelty (See Hypothesis H2a) on solution occurrence, a 2 (Object Novelty: Low vs. High – within subjects) x 3 (Instruction type: NoPS, BroadPS, SpecificPS – between subjects) x 2 (Solution Type: need-solution pair count vs. need-first solution count – within subjects) mixed-effect general linear model was used. Of the three main effects in the model, only the main effect of Object Novelty ($F_{(1,71)}$ = 120.802; $p < 0.0001$) was found to be significant. This significant main effect indicates that independent of solution type, more solutions were found when participants were exposed to visually novel objects (1.67 solutions) than when exposed to visually familiar objects (0.46 solutions) (See Fig. 2). This is consistent with our view that interactions with familiar objects may naturally obscure ad hoc affordances through functional fixedness (Duncker, 1945), and as such, limit solution finding by constraining the solution space.
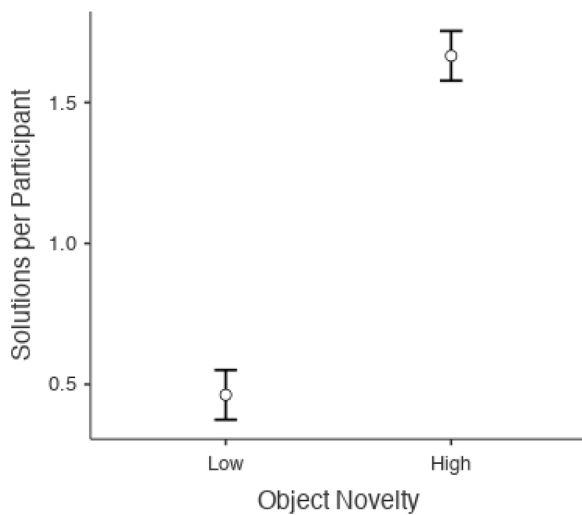
Fig. 2. Interactions with visually novel objects yields more solutions (independent of solution type) than interactions with low visual novelty objects. Error bars depict ± 1SE.

While a significant main effect of solution type was not found, this null effect suggests that the current experimental procedure and design offered balanced support for both the generation of need-solution pair recognition (1.17 solutions) and need-first solutions (0.96 solutions). This however does not mean that our experimental procedures did not influence the occurrence of each solution type. Despite failing to find a main effect of Instruction type ($F_{(2,71)} = 0.019$, $p = 0.987$), we did find evidence that this is likely because of a significant interaction between Instruction type and Solution type. Specifically, as the level of overt instruction to problem solve increased, (1) the occurrence of need-first solutions increased (NoPS: 0.56 solutions, BroadPS: 0.965 solutions, SpecificPS: 1.35 solutions), while (2) the occurrence of solutions by need-solution pair recognition decreased (NoPS: 1.54 solutions, BroadPS: 1.19 solutions, SpecificPS: 0.78 solutions) (See Fig. 3). A post-hoc one-way ANOVA examining need-solution pair occurrence across the 3 types of instruction (See Hypotheses H1a, See Fig. 3) was performed and found to be significant ($F_{(2,71)} = 7.093$, $p = 0.002$;

Observed Power = 0.920; Partial Eta Squared = 0.167). A LSD test revealed that the SpecificPS condition yielded significantly less need-solution pairs than the BroadPS condition (Mean difference = −0.41, SE = 0.199; $p = 0.043$) and NoPS condition (Mean difference = −0.76, SE = 0.201; $p < 0.001$). Similarly, a post-hoc one-way ANOVA examining need-first solution occurrence across the 3 levels of instruction (See Hypotheses H1a, Fig. 3) was performed and found to be significant ($F_{(2,71)} = 4.173$, $p = 0.019$; Observed Power = 0.717; Partial Eta Squared = 0.105). A LSD test revealed that the SpecificPS condition yielded significantly more need-first solutions than in the NoPS condition (Mean difference = 0.79, SE = 0.272; $p = 0.015$).

The notion that need-solution pair occurrence was suppressed as the level of explicit instructions to problem-solve was increased is consistent with our view that constraints to the affordance landscape will hinder need-solution pair recognition (see Hypothesis H1a). According to our framework, an actively considered problem constrains attention to those affordances that are pertinent to the considered problem. In reference to need-solution pair recognition, this constraint to the affordance landscape should place limits on need-solution pair recognition by hindering broad consideration for function. It is also meaningful that our instruction manipulation yielded a drastically different effect on need-first solution behavior than on need-solution pair recognition (see Hypothesis H1b, Fig. 3). As previously mentioned, need-first solution occurrence significantly increased while need-solution pair recognition decreased as the level to explicitly problem-solve was increased. This crossover interaction indicates that the scope of the affordance landscape differentially affects need-solution pair and need-first processes, highlighting that they represent distinct cognitive processes.

Solution Type was also found to interact with Object Novelty ($F_{(1,71)} = 16.494$, $p < 0.0001$) indicating that the occurrence of need-solution pairs were significantly more impacted by Object Novelty than the occurrence of need-first solutions. Specifically, the occurrence of need-first solutions rose from 0.59 solutions to 1.32 solutions (an increase of 0.73 solutions) when exposed to visually novel objects, while the occurrence of need-solution pairs rose from 0.33 solutions to 2.01 solutions (an increase of 1.68 solutions) (See Fig. 4). Post-hoc paired sample t-tests revealed that the effect of Object novelty on need-first solution occurrence ($t_{(73)} = 4.967$, p0. .001) and need-solution pair occurrence ($t_{(73)} = 9.471$, $p < 0.001$) was significant (See Hypothesis
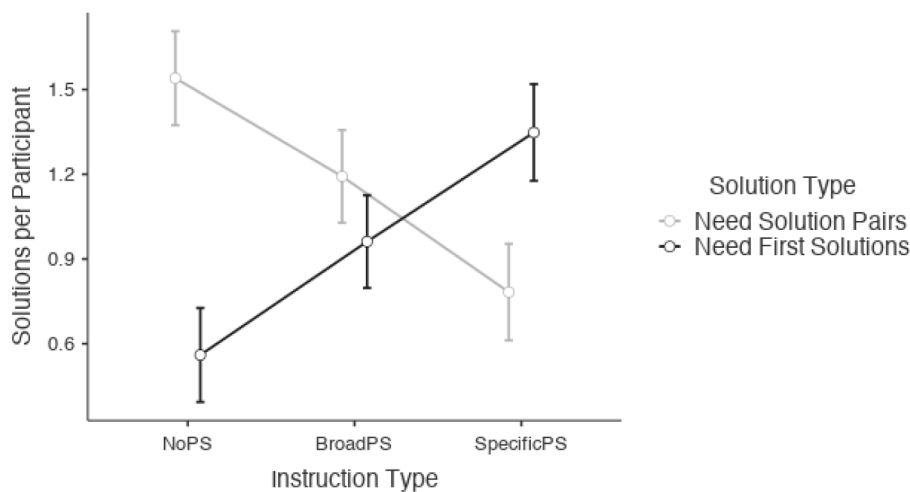

Fig. 3. As overt instruction to problem-solve increases, it differentially affects the occurrence of NSP and NF. NSP occurrence significantly decreases while NF solution occurrence significantly inceases. Error bars depict ± 1SE.
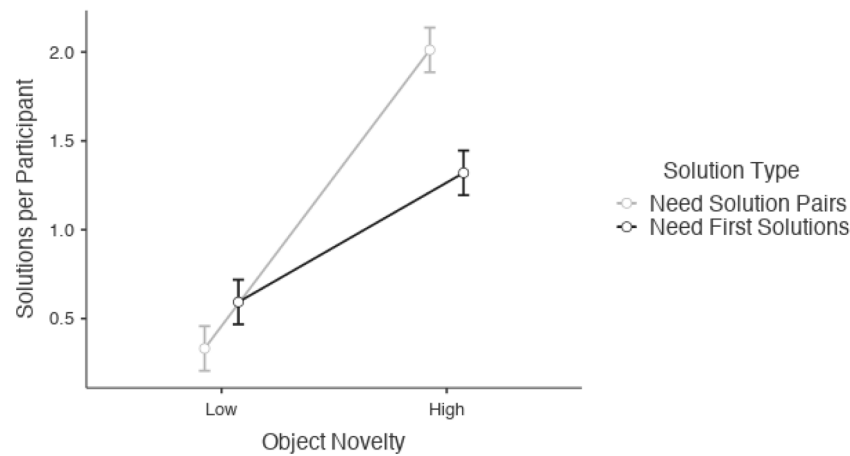
Fig. 4. Interactions with novel versus familiar objects differentially affects the occurrence of need-solution pairs and need-first solutions. Need-solution pair occurrence significantly more impacted by object novelty than need-first solution occurrence. Error bars depict ± 1SE.

H2a/H2c).

While the significant main effect of Object Novelty indicated a general pattern to suggest that interactions with visually novel objects yield more solutions than interactions with visually familiar objects, the significant interaction term between Solution Type and Object Novelty suggests that the effect of Object Novelty was much more pronounced for need-solution pair recognition than need-first problem solving. While not a stated hypothesis, this effect indicates that need-solution pair recognition relies more heavily on ad hoc affordance processing than does need-first problem solving.

Of the remaining terms in the model, the only other significant term found was between Object Novelty and Instruction Type $(F_{(2,71)} = 3.782, p < 0.028)$. While not anticipated by a hypothesis, this interaction suggests that the impact of Object Novelty on solution finding was differentially affected by the level of instruction to explicitly problem solve. More specifically, Object Novelty was found to have the biggest impact on the occurrence of solutions (either by need-solution recognition or need-first problem-solving) in the NoPS condition, and that this impact was lessened when individuals were given either Broad or Specific instructions to explicitly problem solve. (See

Fig. 5). Post-hoc paired-samples t-tests (adjusted for multiple comparisons) revealed that the Object Novelty manipulation yielded a significant difference in the occurrence of solutions for each Instruction Type (collapsed across need-solution pairs and need-first solutions; Bonferroni's t-value adjustment for 2 sided testing at the 0.05 alpha level needs to exceed −2.5912, or 2.5912; NoPS condition $t_{(22)} = -9.070$, BroadPS condition $t_{(22)} = -5.943$; SpecificPS condition, $t_{(22)} = -4.347$). This finding suggests that Object Novelty is a critical factor in invoking solutions when participants are given no instructions to explicitly problem-solve. While solution generation can improve in low novelty settings with more instruction to explicitly problem solve, the reverse is seen in high novelty settings. Specifically, solution generation suffers in high novelty environments as instruction to problem solve becomes more specific. The data are compatible with the view that while highly novel environments may stimulate affordance processing, active consideration of a problem under such circumstances acts only as a constraint on such processing, which in turn hinders solution finding (either by need-solution pair recognition or by need-first problem-solving). The converse however appears to be true in a low novelty environment: active consideration of a problem may be necessary in order
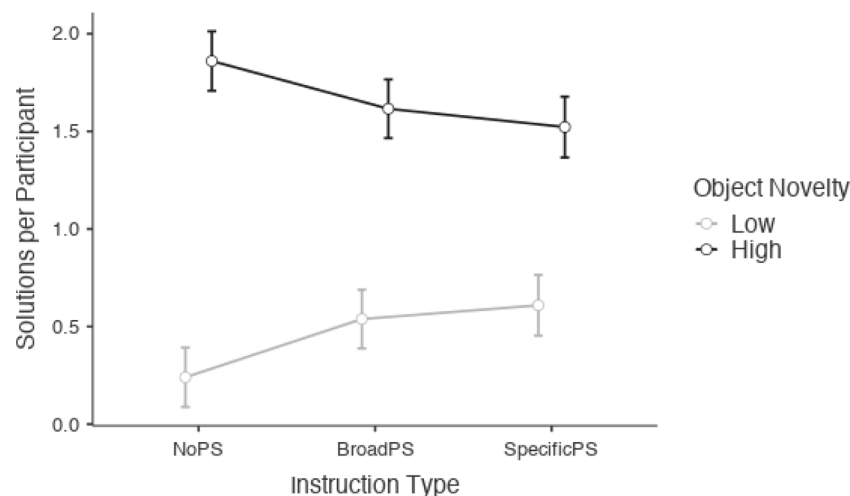

Fig. 5. Object novelty (low vs. high) has the largest impact on solution generation in the NoPS condition, where participants were told to simply explore the room. Error bars depict ± 1SE.
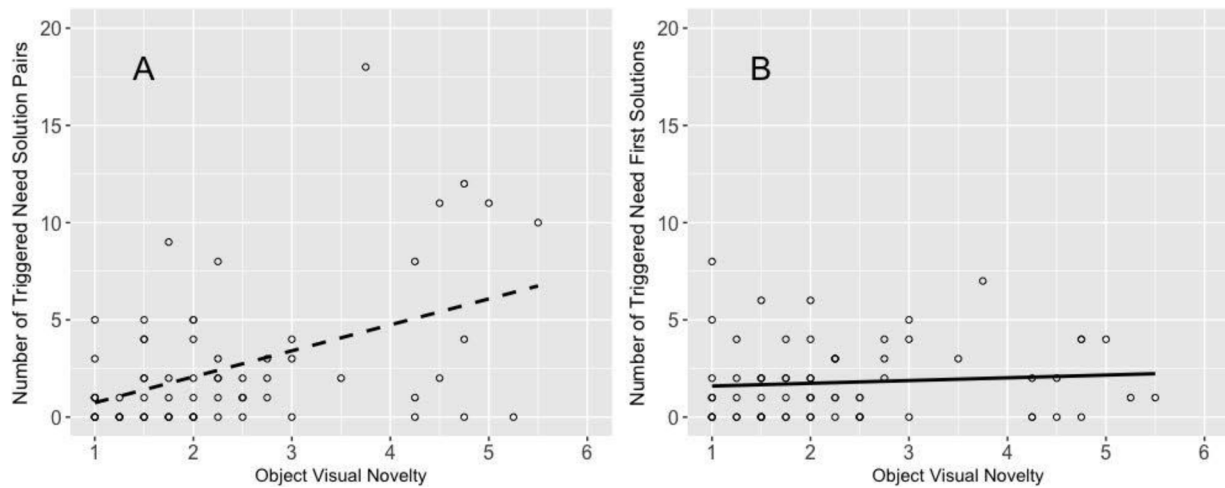
Fig. 6. Linear associations of visual novelty rating for an object and the number of solutions it triggered (Panel A: need-solution pair recognition, Panel B: need-first solution finding). The lines represent the line of best fit. Results indicate that objects that are more visually novel are significantly more likely to trigger need-solution pairs (Panel A). No such relationship however was found between visual novelty and need-first occurrence (Panel B).

to evoke solution finding – by either need-solution pair recognition, or by need-first problem-solving.

5.3. Object novelty in triggering need-solution pairs vs. need-first solutions

Given that participants were able to identify an object or groups of objects that led to their solution 90% of the time (either by need-solution pair recognition or by need-first problem-solving), we examined the relationship between the novelty of an object's appearance (rated by 3rd party raters) and how often it acted as a trigger object for both types of solution finding (see Hypothesis H2b). A regression between the two measures, using the Huber/White correction for heteroskedastic errors, revealed a positive, significant relationship ($t_{(68)} = 2.87$, $p<0.01$), indicating that the occurrence of need-solution pair recognition is linearly related to the visual novelty of objects, such that more visually novel objects have a significantly greater likelihood of eliciting need-solution pairs than visually familiar objects (see Fig. 6a; White, 1980).

We did not find evidence for a relationship between the visual novelty of an object and how often it elicited need-first solutions (Huber/White corrected, $t_{(68)} = 0.6924$, $p = 0.49$, Huber/White corrected) (see Fig. 6b). This finding further supports the notion that object familiarity discourages ad hoc affordance processing (due to functional fixedness), which we have argued supports solution finding by need-solution pair recognition.

5.4. The creativity, novelty, and general value of solutions recognized by our participants

Recall that, in hypothesis H3, we reasoned that solutions resulting from need-solution pair recognition would be higher in creativity and novelty than solutions resulting from need-first problem-solving. We used independent coders, as was discussed in our methods section, to evaluate both the need-solution pairs ($n = 175$) and the NF solutions ($n = 139$) generated by our participants with respect to novelty and
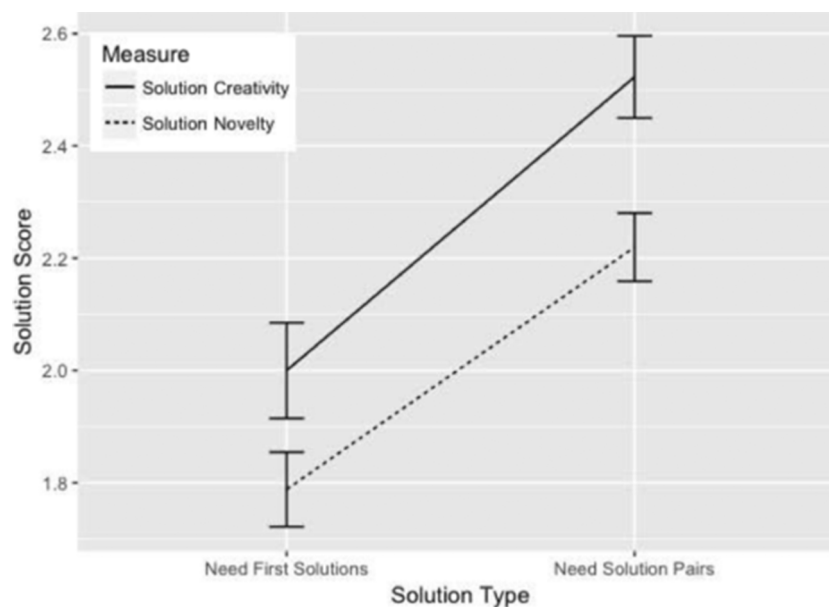

Fig. 7. Assessed creativity and novelty was higher for need-solution pairs than for need-first solutions. Error bars depict $\pm$ 1SE.
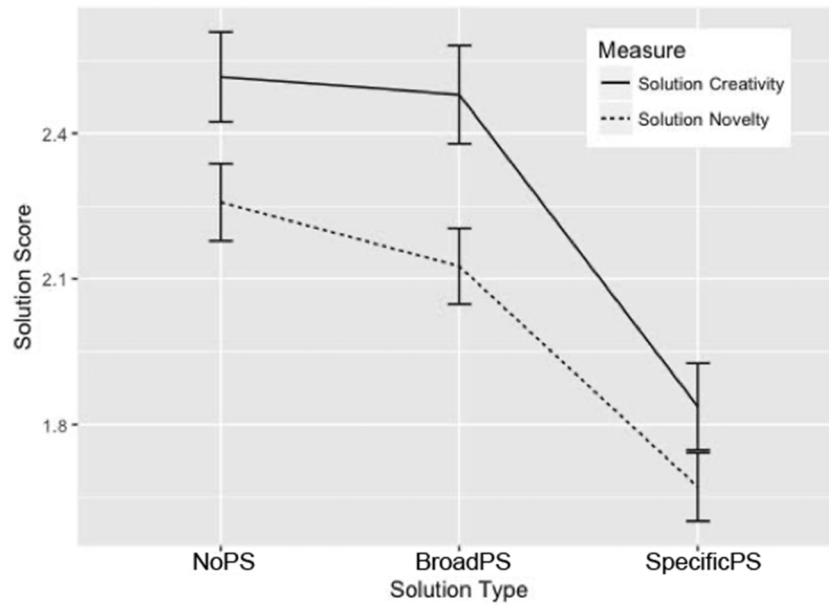
Fig. 8. Solutions generated in the SpecificPS condition had lower assessed creativity and novelty than solutions generated in either the BroadPS or NoPS conditions. Error bars depict ± 1SE.
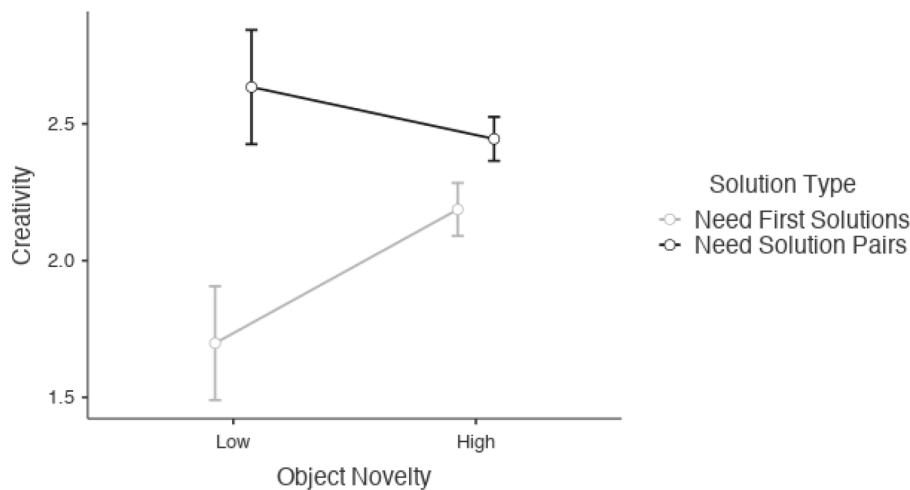

Fig. 9. While NSP solutions demonstrate higher creativity scores than NF solutions, this difference in creativity is exacerbated in the low object novelty condition. Error bars depict ± 1SE.

creativity. In addition to novelty and creativity, we also assessed the value of each solution as proposed by de Jong et al. (2015). To assess if (1) the explicit instruction to problem-solve, (2) the presence of object novelty or (3) solution type influenced the creativity, novelty or value of solutions generated, we utilized a 2 (Object Novelty: Low vs. High – within subjects) x 3 (Instruction type: NoPS, BroadPS, SpecificPS – between subjects) x 2 (Solution Type: need-solution pair count vs. need-first solution count – within subjects) multivariate analysis of variance on the three dependent measures of solution creativity, solution novelty, and solution value.

In support of hypothesis H3, we found a main effect of Solution Type for the dependent measures of solution creativity ($F_{(1, 301)}$ = 13.834, $p < 0.001$) and solution novelty ($F_{(1301)}$ = 12.431, $p < 0.001$). Examination of the means demonstrates that the assessed

creativity and novelty was higher for need-solution pairs than for need-first solutions (See Fig. 7). In addition to the main effect of Solution Type, a main effect of Instruction type was also found for the dependent measures of solution creativity ($F_{(2, 301)}$ = 8.694, $p < 0.001$) and solution novelty ($F_{(2, 301)}$ = 8.213, $p < 0.001$), indicating that at least one of the three instruction types yielded solutions with significantly different creativity and novelty (See Fig. 8). A post-hoc LSD multiple comparison test indicated that the assessed creativity ratings of solutions generated in the SpecificPS condition was lower than solutions generated in either the BroadPS (mean difference: −0.726, SE: 0.174, $p < 0.001$) and NoPS (mean difference: −0.492, SE: 0.216, $p = 0.024$) conditions. The difference between NoPS and BroadPS (mean difference: 0.234, SE: 0.196, $p = 0.234$) did not provide evidence for a significant difference between the two groups (See Fig. 8). An additional post-hoc LSD

multiple comparison test indicated that the assessed novelty ratings of solutions generated in the SpecificPS condition was lower than solutions generated in either the BroadPS (mean difference: -0.5507, SE: 0.141, $p < 0.001$) and NoPS (mean difference: -0.5160, SE:0.175, $p = 0.004$) conditions. The difference between NoPS and BroadPS (mean difference: 0.0347, SE: 0.159, $p = 0.828$) did not provide evidence for a significant difference between the two groups (See Fig. 8).

Further, a significant interaction effect between Object Novelty and Solution Type for the dependent measure of solution creativity ($F_{(1301)} = 4.454$, $p = 0.036$) was found. Inspection of the means indicate that while solutions from need-solution pairs have higher creativity than need-first solutions, that this difference is exaggerated in the low object novelty condition (See Fig. 9). A similar trend, although only marginally significant, was found for the dependent measure of solution novelty ($F_{(1301)} = 3.333$, $p = 0.069$). These results demonstrate that solution finding by need-solution pairs appears to allow individuals to use familiar objects in novel ways, while solution finding that is need-first encourages individuals to use familiar objects in familiar ways. While this result was not necessarily anticipated, it does demonstrate that both forms of solution finding are influenced by the functional understanding of objects.

Lastly, while we did not have a direct hypothesis about solution value, we did find a significant main effect of Object Novelty for the dependent measure of solution value ($F_{(1301)} = 16.766$, $p < 0.001$). Solutions found in low object novelty environments are assessed to have higher value (mean = 3.151, SE = 0.098) than those found in high object novelty environments (2.714, SE = 0.042). This is reasonable, because familiar objects likely possess clear value to individuals. For example, a familiar object such as a hammer may have clear value to participants, as participants can easily remember times they have needed a hammer and used one. For more novel objects, that experience is not available, and as such, the value of the object is likely to be less clear to participants. Note that this finding was restricted to object novelty: we failed to find a significant difference in the general value of solutions recognized via need-solution pairs, and those discovered via a need-first process ($F_{(1301)} = 0.817$, $p = 0.367$).

6. Discussion

The main contributions of this paper have been (1) to produce empirical evidence for the occurrence of need-solution pair recognition in the minds of individuals, (2) to provide an examination of a cognitive account for how need-solution pair recognition may arise, and (3) to assess the creative value of need-solution pair recognition relative to need-first solution finding. As we have previously discussed, solution finding has been traditionally conceived of as a process that begins with the identification of a need or problem, followed by attempts to solve it (Newell and Simon, 1972; Sternberg et al., 2014). The contributions of this current study however, challenge the universality of this traditional conception. Rather than postulate that solution finding is a product of a need-first process, the mechanistic account supported by our data suggests that solutions may arise from the functional consideration of objects. Moreover, solutions found by need-solution pairs were found to be more creative and novel than solutions found by a need-first process, highlighting that the practice of need-solution pair recognition may be best suited to situations requiring highly innovative solutions.

6.1. Evidence for need-solution pair recognition and its potential pervasiveness

Recall that our experimental results demonstrated that not only do

solutions by need-solution pair recognition occur, but that they can occur more frequently than solutions found using a need-first solution finding strategy under the right circumstances. While our current experimental procedure and design as a whole, balanced support for the generation of both need-first solutions (0.96 solutions) and those found by need-solution pair recognition (1.17 solutions), we did find experimental support that under some contexts, need-solution pair solutions dramatically outpaced solution finding via traditional need-first strategies. This suggests that need-solution pair discoveries may be at least as frequent in practice as need-first solution finding given appropriate circumstances.

Given this striking finding, a first question we must ask is – how could the ubiquity of need-solution pair recognition have been missed over all these years by prior empirical research on problem-solving? We think there are two major reasons. First, problem-solving researchers very generally have designed their research around studies of how experimental subjects solve a problem *specified in advance* within their experimental protocols (Newell and Simon, 1972; Sternberg et al., 2014). Thus, an experimenter may ask subjects to 'list all the words you can bring to mind beginning with the letter C in the next two minutes'. Similarly, recall that Dunker conducted his classic research on problem-solving by posing to his experimental subjects problems such as the "candle problem: 'Solve the problem of attaching a candle to a wall in such a way that the candle wax won't drip onto the table below. To do so, you can only use a candle, a book of matches, and a box of thumbtacks'. As we saw in the finding section of this paper, need-solution pair occurrence was highest when everyday individuals were told to simply explore an environment with no explicit instruction to problem-solve. In other words, prespecifying a problem to be solved had the effect of greatly reducing frequency of need-solution pair recognitions among our subjects.

Second, experimenters who engage in need-first experiments very generally do not ask about or document any need-solution pairs that may nonetheless be occurring within the minds of their experimental subjects. Thus, as we mentioned earlier, an experimenter who asks individuals to "list all the words they can bring to mind that begin with the letter C in two minutes" will not ask about or document any need-solution pairs that might be evoked in a participant's mind – perhaps triggered by a novel object that happens to be present in the experimental setting. Similarly, an experimenter who presents Dunker's classic candle problem to participants in order to observe how they solve that specific problem will not be primed to ask about or document any need-solution pairs that might spontaneously be recognized by some participants in that setting, e.g.: "It just occurred to me that I can use wax such as from the candle you provided in your experiment to fill a crack in the antique desk I have at home."

6.2. Value of need-solution pair recognition for householders

As we noted in the introduction to this article, we think that need-solution pair recognition will be especially valuable in the case of householder problem-solving or solution recognition practices. We propose two major reasons for this. First, need-solution pair recognition is inherently very low cost and quick, and so compatible with levels of resources available to householders. After all, recognition of a pair is an instant, monetarily costless cognitive activity in the mind of an individual. Second, householders are likely to find a higher fraction of need-solution pairs they recognize to be of value to them than would be the case for firms evaluating need-solution pairs recognized by their employees. We elaborate on this very important matter next.

Consider that, in the case of need-first problem-solving, in the

course of framing a problem, solvers generally also give at least some consideration to whether the as-framed problem will be *worth* solving from their perspective. That is, an individual or firm will try to assess whether the benefits of a solution to *that problem*, once developed, will justify the investment required. In sharp contrast, in the case of need-solution pair recognition, there is no pre-formulated problem. As a result, assessment of the value of each need-solution pair recognized must come *after* the recognition event. If this assessment of value is also quick and informal, as it is likely to be in the case of household problem-solving – "Sure, going out to dinner this evening to try out that new restaurant serving X cuisine sounds like fun, let's do it" - then the cost to a householder of such post-hoc filtering is likely to be low. In contrast, the valuation assessment process is likely to be much more complex and costly in the case of firms evaluating the value of a proposed need-solution pair –simply because much more sunk and follow-on investment is on the line. Thus, a decision to *build* a new restaurant to serve X cuisine is likely to involve much more investment in investigation of the likely general demand for that type of restaurant.

It is also likely that the fraction of need-solution pairs evoked of potential use to householders is higher than would be the case for producers. This is simply because individual householders are end users of many more products and services than any specific firm produces. For example, a householder may find both a need-solution pair involving novel kitchen flooring *and* a need-solution pair involving a novel food recipe to be of potential personal utility. In contrast, a producer of kitchen flooring will find only the first need-solution pair to be potentially profitable, due to existing investments and specialization in that specific type of products.

6.3. Higher creativity when problems are not pre-specified

Recall that need-solution pairs were found to have higher creativity and novelty than those recognized as need-first solutions. This finding was in line with our hypothesis that conditions that allow need-solution pair recognition to thrive (such as, no explicit instruction to problem-solve and high visual object novelty in the environment) would also be suitable for supporting creative analogical reasoning and less functionally fixed affordance processing. Work by Sternberg (1977) as well as work by Holyoak and Thagard (1995) both have argued that analogies that bridge larger semantic distances are generally perceived as more creative than those that bridge smaller distances. This is because distant analogies by definition allow for juxtapositions that illuminate features of objects or ideas that are novel. Indeed, work by Christensen and Schunn (2007) has demonstrated that interactions with familiar objects often inhibit analogical reasoning due to functional fixedness.

Further, freedom from an actively considered problem might allow one greater access to the full affordance landscape of an environment. This is because having a specific problem in mind likely directs attention towards particular functions or aspects of objects that relate to the specific problem at hand. Under this view, the specific problem being pursued acts as an attentional filter on the recognition process, constraining how one approaches the affordance landscape. This observation also suggests that need-solution pair recognition may flourish under situations involving open monitoring, a mental state where individuals are not focused on any particular concept, item, or goal (Tang et al., 2015). Consistent with this view are results from previous research, which has demonstrated that individuals who regularly practice the open-monitoring of attention (through open-monitoring meditation) are better at overcoming effects associated with functional fixedness than those that practice focused-attention (through focused-attention meditation) (Colzato et al., 2012).

6.4. Object novelty supports need-solution pair recognition

We also found clear evidence that interactions with objects with high novelty to a subject led to significantly more need-solution pairs than interactions with objects with low novelty. Further, a significant positive relationship was found between an object's assessed visual novelty and the number of times the object triggered a solution through need-solution pair recognition. Why would object novelty support need-solution pair recognition? As previously discussed, past research has shown that affordance processing becomes more rigid and tied to past experience once a particular usage for an object has been reinforced (Duncker, 1945). From this perspective, familiar objects naturally suppress ad hoc affordance processing (due to functional fixedness), which necessarily constrains the affordance landscape, hindering need-solution pair recognition.

While the effect of object novelty is strongest on the occurrence of need-solution pair recognition (as evidenced by a significant interaction between object novelty and solution-type), the overall significant main effect of object novelty indicates that both types of solution finding are beholden to the same object recognition mechanism, just to differing degrees. This finding suggests that, in a very general sense, solutions appear to emerge from the functional consideration of objects, whether constrained or unconstrained by a problem. This observation highlights that the perceptual-cognitive mechanism put forth here for need-solution pair recognition can be parsimoniously extended to need-first solution finding, and can for example, be utilized to offer insight as to why functional fixedness hinders traditional problem-solving (Adamson, 1952; Allen and Marquis, 1964; Chrysikou and Weisberg, 2005; Duncker, 1945; Luchins, 1942; McCaffrey, 2012).

6.5. Suggestions for further research

Our research has demonstrated that solutions generated in the minds of individuals appear to often emerge from the functional understanding of objects. Given the fundamental importance of solution finding to individual and social functioning and societal progress in general, it would clearly be useful to conduct research to more deeply understand this form of thinking. A few suggestions to this end follow.

First, recall that, while our experiment focused on physical objects, we hold that our results will generalize to other kinds of objects such as processes or algorithms, provided that individuals reason about their affordances. Despite not being tangible entities, it seems sensible that one can reason about the function of a given process, a given procedure, a given algorithm, or even a given idea - and from such reasoning, come to understand the given entity (or aspect of the entity) as a solution to a previously unknown problem. For example, while genetic hill-climbing algorithms were initially used to model the process of natural selection, they have had application in a number of disparate areas such as the optimization for traffic routing (e.g., the 'Traveling Salesman Problem'), code breaking, and even the generation of virulent Internet memes. While some of these applications may have been generated via a need-first process, it is conceivable that some are the result of need-solution pair recognition - happened upon only through the consideration of what the algorithm could be used for either consciously or unconsciously. Further research would clearly be valuable to demonstrate that need-solution pair recognition can occur for non-tangible objects. Also, it will be important to determine whether the functional consideration of such non-tangible objects is affected by conventional usage, as we saw to be the case for tangible objects. In this way, one could determine whether solution finding with non-tangible objects is also hindered by functional fixedness.

Second, in future research it will be important to better understand

the suppressive effect that pre-specification of a problem has on solution finding in general, especially with regard to need-solution pair solution finding. Experimenters who engage in need-first experiments very generally do not provide a path for noticing or documenting need-solution pairs that may nonetheless be occurring within their experiments. Thus, as we mentioned earlier, an experimenter who asks individuals to "list all the words they can bring to mind that begin with the letter C in two minutes" will not consider asking about or documenting a need-solution pair that might be evoked in a participant's mind – perhaps triggered by a novel object that happens to be present in the experimental setting. For many research purposes, it will certainly be useful to pre-specify a problem and limit inquiry to only solutions that satisfy that given problem. Still, when exploring need-solution pairs and the role of object recognition, it will be important to treat pre-specification of a research problem not as a given, but as an experimental variable.

Third, beyond simply being aware that need-solution pair recognition may be occurring in need-first contexts, it will be important to look beyond the situational effects observed here and examine how individual differences in the neural, perceptual and cognitive factors may also impinge on need-solution pair recognition. For example, at the neural level previous work has demonstrated that activity in fronto-polar cortex (FPC) supports analogical coupling (Holyoak and Thagard, 1995; Mayer, 1999) and therefore, may in part explain individual differences in need-solution pair recognition. Similarly, individuals with high working memory, or a strong ability to actively maintain information for the purposes of ongoing cognition, have been shown to possess better analogical reasoning (Corkill and Fager, 1995; Novick and Holyoak, 1991; Stanovich, 1999). As such, individual differences in working memory may explain meaningful inter-individual differences in need-solution pair recognition ability. Further, beyond better understanding for the neural, perceptual, and cognitive factors that may support need-solution pair recognition, it also remains an open scientific question as to whether individual differences in need-solution pair recognition reflect some biological endowment or whether such differences arise as the result of experience and as such can be influenced by training and practice.

Fourth and finally, recall that, according to participant self-report in our experiment, solutions by need-solution pair recognition were accompanied by a subjective "aha" or "eureka" feeling, which could prompt the comparison of need-solution pair recognition to need-first problems that are unexpectedly solved (a process sometimes referred to as insight problem-solving). While solutions found by need-solution pair recognition also appear to occur spontaneously, we hold that need-solution pair recognition is a markedly distinct form of insight. According to research on need-first insights, there is empirical evidence to suggest that in order for a need-first insight to be achieved, one must first attempt to solve a problem that results in an impasse (i.e. a failed attempt at solving the problem). Indeed, research by Vul and Pashler (2007) has demonstrated that need-first insights only occur if one initially uses an inappropriate strategy or are initially given misdirecting information when approaching a problem. Simply knowing or formulating the problem is not enough. This suggests that the occurrence of need-first insights relies not only on explicit problem formulation, but a clear previous attempt, met in failure, to solve a

problem. This aspect of need-first insights is not compatible with the need-solution pair 'insights' observed in our experiment, and as such suggests that need-solution pair insights are precipitated, at least in part, in a different manner from need-first insights.

While need-solution pair recognition offers a mechanistic account for how some serendipitous solutions may arise, we wish to note that future work should be cautious with respect to equating need-solution pair recognition with the phenomenon of 'serendipity.' While need-solution pairs may be classified as 'serendipitous', the label (at least historically) offers little insight into the processes that may underlie its occurrence. Indeed, the approach to serendipity has been largely phenomenological, with some scholars including need-first insights, or the unexpected discovery of a solution to a problem already being worked upon, as an accepted form of serendipity (for a full taxonomy of serendipity, see Yaqub, 2018). The notion that both need-first insights and need-solution pair insights can be thought of as examples of serendipity highlights clearly that need-solution pair recognition and serendipity are not synonymous.

6.6. Conclusion

Our empirical demonstration of the cognitive mechanism underlying need-solution pair recognition in the minds of everyday individuals indicates that such discoveries are a product of an orderly perceptual-cognitive process. This finding suggests that such discoveries may be cultivated through appropriate training and practice. Rather than suppose that solutions sometimes occur by chance, our findings suggest that a large subset of serendipitous solutions - from antibiotics to Velcro – could very well be better characterized as resulting from need-solution pair recognition via functional object understanding. We invite future work to consider the broad implications of this result – spanning from how one should design curricula that encourage this mode of thinking in the household sector, to how we should structure our institutions in order to foster need-solution pair discoveries beyond the household sector.

Credit author statement

All co-authors participated in all elements of this research project.

Declaration of Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Examples of Solutions Found

Object novelty	Instruction type	Need-Solution pair	Trigger object
High	NoPS	**"Digital kaleidoscope"**: While inspecting a miniature camera lense in the cabinet, one participant had the idea to create a kaleidoscope like device that would display randomly generated images by using digital technology including visually enhanced effects. Both - effects and pictures generated - would constantly change by turning the digital kaleidoscope around.	Miniature camera lense
High	NoPS	**"Bottle with integrated ice cubes"**: Another participant came up with a new idea to more conveniently produce and use ice cubes at home. The participant spotted an oddly shaped white bottle in the cabinet and had the idea of a plastic bottle with bumps which could be filled with water and put in the fridge to create ice cubes. Such integrated icecubes are then seemlessly distatched when liquids are filled into the bottle.	Oddly shaped figure
High	NoPS	**"Magnetic sealing mechanism for pots"**: Inspired by the tactile feeling gained from handling a microwave pot from the cabinet, one participant invented a magnetic lip to hold covers onto cooking pots: *"I liked and enjoyed the feeling of snugness while opening and closing the microwave egg cooking pot – given the rubber lip, the lid smoothly stuck on the pot. Based on this experience, I envisioned a magnet mechanism for sealing pots."*	Microwave pot
Low	Broad PS	**"Throw game"**: Inspired by a tea container with different pockets, one subject invented a throw game in which one had to tactically place ping pong balls into different fields.	Tea container
High	NoPS	**"Magnetic tools"**: One participant spotted a hammer with a magnet placed on the back in the cabinet. This object triggered the idea to magnetize the other end of the hammer to facilitate pinning nails in wood.	Hammer with magnet attached

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