Proceedings of the ASME 2017 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference
IDETC2017
August 6-9, 2017, Cleveland, Ohio, USA

Draft of DETC2017-67513

OBJECT REORIENTATION AND CREATIVE PERFORMANCE

A.-M. Olteţeanu
Bremen Spatial Cognition Center
University of Bremen
Enrique-Schmidt-Str. 5
28359 Bremen, Germany
amoodu@informatik.uni-bremen.de

L.H. Shu*
Department of Mechanical & Industrial Engineering
University of Toronto, 5 King's College Road
Toronto, ON, M5S 3G8, Canada
*Corresponding author email:
shu@mie.utoronto.ca

ABSTRACT

Functional fixedness refers to a cognitive bias that prevents people from using objects in new ways, and more abstractly, perceiving problems in new ways. Supporting people in overcoming functional fixedness could improve creative problem solving and capacities for creative design.

A study was conducted to detect whether a relationship exists between participants' tendency to re-orient objects presented as stimuli in an Alternative Uses Test and their creativity, also measured using the Wallach Kogan pattern meanings test. The Alternative Uses Test measures creativity as a function of identifying alternative uses for traditional objects. The Wallach Kogan pattern-meanings test detects the ability to see an abstract pattern as different possible objects or scenes. Also studied is whether the Need for Closure scale, an individual measure reflecting aversion to ambiguity, can predict the ability to use reorientation productively to reduce functional fixedness.

This study revealed highly significant, high correlations between reorientation and several creativity measures, and a significant medium correlation between reorientation and Need for Closure scores. A qualitative exploration of participants' responses reveals other strategies they used to overcome functional fixedness, as well as further metrics that may be relevant to assessing creativity in the Alternative Uses Test.

1 INTRODUCTION

Imagine yourself in a bathtub, that place famous for generating creative ideas, and suddenly instead of experiencing a light-bulb moment, a bulb explodes, leaving you in complete darkness. Knowing that shards of glass will now be scattered everywhere, how would you get out safely to address the bulb problem? Alternatively, imagine discovering a wardrobe malfunction ten minutes before a very important meeting, just before heading out of your office door. How would you still arrive at the meeting on time, without access to a change of clothes? Or imagine being tasked with obtaining a set of objects to improve productivity in the office space of an entire team, with only a budget of 50 dollars to do so. What would you buy?

These are ill-structured problems, the solution of which requires creative thinking and sometimes, recognizing alternative uses for objects, beyond the typical ways of thinking about such objects. In the above situations, nearby towels could serve as potential carpets over the broken glass, and a stapler could perhaps remedy a wardrobe malfunction. Finally, a set of bowls could be used to hold to-do lists, alerting chatty employees, and managers from further delegating tasks to the employees with literally full bowls, despite their efficiency.

As ill-structured problems typify real-world and design problems, we aim to identify strategies that can be used to boost creativity in problem solving. This paper investigates the possible relationship between uptake of cues to reorient stimulus objects, i.e., examine them from different perspectives, and the ability to identify creative object uses. We also examine participants' strategies when coming up with new uses for both concrete objects and more abstract pattern stimuli.

2 BACKGROUND

2.1. Functional fixedness

Functional fixedness is a cognitive bias that may constrain design and problem-solving creativity through preferential consideration of objects with the same, past functions. While conducting empirical insight problems using objects, Duncker (1945) observed functional fixedness manifested as participants' inability to consider different new uses and functions for well-known objects. Such functional fixedness led participants to repeat the same set of unfeasible solutions they identified, while being unable to consider new, more productive solutions.

Creative solutions, which may arrive in a moment of insight, generally require an ability to restructure and/or re-represent the problem (Batchelder & Alexander 2012; Ohlsson 1983-4; Olteţeanu 2015a). In addition, corresponding objects, both concrete and abstract, must be considered in new, creative ways.

2.2. Alternative Uses Test (AUT)

Creativity tests empirically assess human creativity by measuring various abilities. For example, the Alternative Uses Test (AUT) asks participants to identify as many uses as they can for ordinary objects such as a *brick* or a *paperclip* (Guilford 1956, 1967). Participant responses are evaluated using various metrics. For example, *Fluency* measures the number of uses the participant produces. *Flexibility* reflects how many of these uses are conceptually different or belong to different semantic domains. For example, using a *brick* to *press a newspaper* and *as a paperweight* describe the same conceptual use.

The AUT is usually administered using words that refer to objects, rather than with image stimuli that represent particular instantiations of objects. The two seemingly similar situations differ from a cognitive perspective. That is, a participant given a word referring to an object is more likely to be provided a particular concept that they can instantiate in their imagery in different ways. In contrast, a visual stimulus is a particular instantiation of an object which might in some ways direct (and in other ways restrain) the uses the participant may identify.

For example, imagine being asked to think of all the uses for a *glove*. If a photograph of the glove is provided, a decision must be made as to whether the glove is a winter glove (worn because it is cold), a gardening glove (worn to protect from thorns), or a medical glove (worn to protect from germs and contamination). Giving *glove* as a verbal stimulus does not require specification on the nature of the glove's material. In contrast, it is less likely that a photograph of an object does not simultaneously depict some information about material. Therefore, a visual instantiation of an object can by nature be more specific than the word referring to that object. In addition, visual suggestion of specific use contexts for the object further promotes functional fixedness. In related work on fixation, Linsey et al. (2011) observed the importance of viewing method on idea generation.

To support creativity for design, which deals with both concrete and abstract concepts, the current work administered the AUT using photographs of concrete objects, which still retain some ambiguity (Zeki, 2004).

2.3. Need for Closure (NFC)

Social psychologists Kruglanski & Webster (1993) developed the Need for Closure (NFC) Scale as an individual difference variable. Someone with a high NFC tends to want to quickly attain cognitive closure. This is manifested through frantic 'seizing' on early and readily available cues, to come to a quick evaluation, followed by a stage of 'freezing' or protecting that evaluation. Plaks (2011) describes those with high NFC as more likely to make snap judgments and stereotype. Meanwhile, those with low NFC (or a high need to avoid closure) might find it harder to form judgments for even the most trivial matters, e.g., deciding what to order from a restaurant menu. Paradoxically, evaluating fewer competing hypotheses may lead to a higher sense of confidence in the possibly incomplete evaluation. The tendency of those with high NFC to rely more on early and readily accessible cues appeared to be closely related to susceptibility to functional fixedness, where participants who were primed with possible uses experience more difficulty identifying other uses for objects. Therefore, the current work also aims to investigate the relationship between NFC and the productive use of reorientation for creative tasks.

Kruglanski & Webster (1993) devised a formal measure of dispositional NFC, validated by Webster & Kruglanski (1994). This NFC Scale has the following 5 subscales and corresponding sample statements: 1) Order and structure: *I enjoy having a clear and structured mode of life*; 2) Ambiguity: *I'd rather know bad news than stay in a state of uncertainty*; 3) Decisiveness: *I usually make important decisions quickly and confidently*; 4) Predictability: *I don't like to go into a situation without knowing what I can expect from it*; 5) Closed mindedness: *I do not usually consult many different options before forming my own view*. To such statements, respondents select degrees of agreement from 1) Strongly disagree to 6) Strongly agree. For the above statements, "Strongly disagree" contributes 1 point, and "Strongly agree" contributes 6 points to the total NFC score. Other statements are reverse-scored, i.e., expressed such that a choice of "Strongly disagree" adds a score of 6 to the NFC scale. The above five subscales are measured using a total of 42 statements, all scored on a 6-point scale, resulting in total NFC scores in the range of 42 (low) – 252 (high). Someone with a high NFC generally has: a preference for order and structure, discomfort with ambiguity, high decisiveness, desire for predictability, and high close-mindedness. Conversely, someone with a low NFC would have the opposite characteristics.

On a related note, Toh & Miller (2016) developed a 23-item psychometric scale to assess individual preference for creativity during concept selection in engineering design on 4 dimensions: (1) Team Centrality, (2) Risk Tolerance, (3) Creative Confidence/ Preference, and (4) Motivation.

2.4 Relation to authors' previous work

Lai & Shu (2017) showed that those with a high NFC tended to fixate, when generating concepts, to elements of a shown example. The current work aims to determine whether NFC has a similar relationship with functional fixedness.

In addition, Lai & Shu (2014) studied do-it-yourselfers (DIYers) who repurpose furniture and other items, noting their ability to recognize possible uses that are not obvious to average users. Studying such DIYers may thus reveal principles relevant to overcoming functional fixedness. Lai & Shu focused on the online community at www.ikeahackers.net, where DIYers post 'hacks' that involve physical modifications to IKEA products, to support new aesthetics or new uses. Strategies that may aid in overcoming functional fixedness were generalized from some of the hacks, particularly those that changed the function of the hacked product. Specifically, one strategy involved reorientation, e.g., a bowl turned upside down to make a lampshade, and a breadbox mounted sideways to create a mailbox. The current work further studies the relationship between the strategy of reorientation and overcoming functional fixedness, as well as creative output.

3 EXPERIMENT

3.1 Participants and procedure

Thirty-seven volunteer participants included fellows and research staff at the Hanse-Wissenschaftskolleg (HWK) in Germany. The HWK is an institute of advanced study that has four research areas: energy, earth, brain and society, in addition to hosting resident artists and writers. Participants also included senior undergraduate, graduate students, and postdoctoral research staff from three research institutes, two in engineering and one in psychology at the Technical University of Braunschweig (TUB) in Germany. The experiment was conducted online and did not impose time limits. Initial data gathered include gender, age range, English proficiency, level of education, self-assessed creativity, and consent for use of data.

3.2 IKEA objects AUT

Pictures of 12 IKEA products were selected to determine whether participants' ability to identify creative uses for them is related to their propensity to reorient these objects. These objects were presented in the default position, or rotated clockwise 90 and 180 degrees to construct the stimuli variants. The images did not contain adjacent objects, which permitted their rotation without having to remove objects or backgrounds.

Purposely included in the stimulus set were ambiguous objects, as ambiguity regarding the objects' intended use may encourage identifying creative alternative uses. Ambiguity regarding size is inherent when an object is presented without other reference objects, the sizes of which are unambiguous, that can be used to determine the size of the presented object. Without further specification, ambiguity regarding the material of the presented object may also remain. For example, a white-colored object could be made of either plastic or ceramic/enamel.

Three participant groups were presented with 3 sets of stimuli, with each set containing 4 objects in the default orientation, 4 at 90° and 4 at 180°, as shown in Table 1. The 12 IKEA objects, shown in Table 2, were presented in random order.

Table 1. Object orientations for the three groups

Object	Group 1	Group 2	Group 3
O1	0°	90°	180°
O2	90°	180°	0°
O3	180°	0°	90°
O4	0°	90°	180°
O5	90°	180°	0°
O6	180°	0°	90°
O7	0°	90°	180°
O8	90°	180°	0°
O9	180°	0°	90°
O10	0°	90°	180°
O11	90°	180°	0°
O12	180°	0°	90°

Participants were asked to propose at least three uses for each of the 12 IKEA objects presented in orientations according to participants' allocated groups. No training example was given, to avoid influencing participants towards uses involving the object either only in the default or in rotated positions as well.

Kumar & Mocko (2016) noted that it is important to be able to compare problems used in creativity research. Marshall et al. (2016) compared verbal and pictorial representation of analogies for concept generation, and found the pictorial version led to more novel ideas than the verbal-only version. Lenau et al. (2015) observed more innovative solutions from students given *biocards* with abstract descriptions compared to concrete descriptions. It was therefore unclear whether an AUT that uses concrete images of specific objects measures creativity in the same way as the traditional AUT that uses words referring to objects. Therefore, a second measure of creativity was deployed.

3.3. Wallach Kogan pattern meanings test (WK)

The pattern meanings test is part of the classical battery of Wallach Kogan tests, where participants are asked to identify what a given abstract pattern could represent. The pattern meanings test is a different way to detect the ability to see a set of features as different potential objects or scenes. It uses test stimuli that are more abstract and ambiguous than the AUT using pictures depicting IKEA objects. Therefore, this test was considered a good measurement of creativity to balance the new form of deployment for the AUT. Figure 1 shows the four Wallach Kogan pattern meaning stimuli (Wallach & Kogan 1965) used in the experiment. Possible interpretations of the top left figure include: a lollipop, a Ferris wheel, a tree, a rotated Pacman symbol, etc. After the IKEA objects, the Wallach Kogan pattern meanings stimuli were presented, with the instruction: *What do you think this could be? Please give as many answers as possible*. Participants who spend less than 15s per stimulus on the Wallach Kogan Test were excluded.

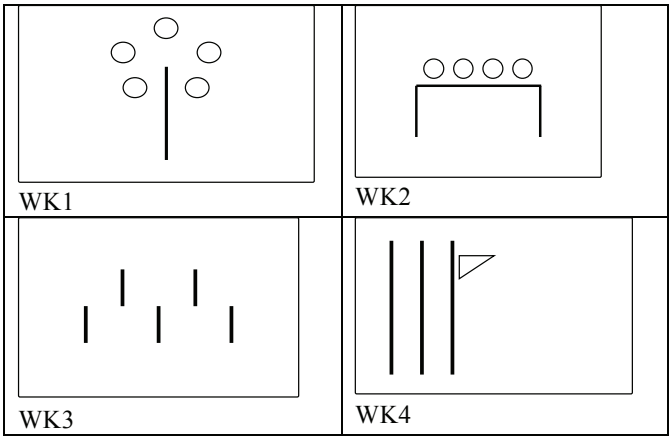

Figure 1: Wallach Kogan patterns used in pattern meanings test.

3.4. Need for closure

Finally, participants completed the NFC questionnaire, which contains 47 statements, using the Likert scale described above. In addition to the 42 statements that measure the above subscales, 5 statements are intended to measure whether a participant is lying. One example statement is: *I have never known someone I did not like.* The scores on the 5 lie-scale statements are summed, and participants whose lie score exceeds 15 were excluded.

Table 2. Stimulus objects for IKEA objects AUT

ID	*Name*	*Default orientation*	*90º orientation*	*180º orientation*
O1	Roller blind			
O2	Glass domes			
O3	Toilet brushes			
O4	Drum night-stand			
O5	Coffee table			
O6	Toilet roll holder			
O7	TV stand			
O8	Plastic bowls			
O9	Gold bowl			
O10	Storage box			
O11	Maga-zine files			
O12	Glass vase			

3.5 Evaluation procedure

The IKEA objects AUT was evaluated on *Reorientation*, *Fluency* and *Flexibility* (low constraints definition).

Reorientation was measured in two ways. In both, a default orientation was determined for each object, independent of whether the object was shown in this default orientation. To illustrate, a possible response for object O5 (coffee table) is: *table, vertical shield, swing attaching rope to legs*. The *table* maintains the default orientation and use, the *vertical shield* requires a 90º reorientation, and the *swing attaching rope to legs*, a 180º reorientation. Using the first measure of reorientation, this response received a score of 1, as it involved at least one reorientation from default. The second reorientation measure was developed to distinguish participants who had more than one reorientation from default. The above response that included uses which required 90º and 180º reorientations would receive the maximum reorientation score of 2 for this object. Multiple uses that correspond to the same reorientation, e.g., *table* and *bench*, only contributed a single point to this reorientation score. This second measure was called *Reorient-24,* as summing non-default orientations over 12 objects leads to a maximum score of 24. A rubric was developed and used to consistently determine orientations for both schemes.

Regarding the other creativity metrics, the uses *table, shield, swing,* for the coffee table would score 3 points on *Fluency* and 3 points on *Flexibility*. A similar evaluation was applied to responses to the Wallach Kogan pattern stimuli, which were always presented in default orientation.

3.6 Results

Table 3 shows the total and per stimulus times and standard deviations for IKEA objects AUT and Wallach Kogan pattern meanings test. Table 4 shows descriptive statistics for the measures *Reorientation, Fluency, and Flexibility* for IKEA objects AUT and the Wallach Kogan pattern meanings test.

Table 3: Average time, standard deviations in total/per stimulus

	$t_{ave\text{-}total}$ (min)	SD (min)	$t_{ave/stimulus}$ (sec)	SD (sec)
IKEA AUT	20.53	8.66	103.6	43.72
Wallach Kogan	5.32	2.41	83.37	41.1
NFC	10.87	3.11	-	-

Table 4. Descriptive statistics for 3 measures (n=33)

Stimuli	**Measurement**	**Mean**	**SE**	**95% LB**	**95% UB**
IKEA AUT	*Reorientation*	7.27 (SD=2.25)	0.39	6.47	8.07
	Reorient_24	9.97 (SD=3.92)	0.72	8.50	11.43
	Fluency	3.41 (SD=0.84)	0.15	3.11	3.71
	Flexibility	3.21 (SD=0.81)	0.14	2.92	3.49
Wallach Kogan	*Reorientation*	1.75 (SD=1.25)	0.22	1.31	2.20
	Fluency	2.83 (SD=1.11)	0.19	2.44	3.23
	Flexibility	2.70 (SD=1.01)	0.18	2.35	3.06

3.6.1 Reorientation and creativity metrics

Table 5 shows that for both the IKEA objects AUT and the Wallach Kogan pattern meanings test, high and highly significant correlations were observed between *Reorientation* and the metrics describing creative performance, *Fluency* and *Flexibility*. Thus the higher the *Reorientation* score of the participants, the higher their creativity as measured with the *Fluency* and *Flexibility* metrics on each of the creativity tasks separately and on both in total.

Table 5. Correlations between factors, all $p < 0.001$

Factor 1	Factor 2	r
Reorientation IKEA AUT	*Fluency* IKEA AUT	0.56
Reorientation Wallach Kogan	*Fluency* Wallach Kogan	0.56
Reorientation total score	*Fluency* total score	0.67
Reorientation IKEA AUT	*Flexibility* IKEA AUT	0.57
Reorientation Wallach Kogan	*Flexibility* Wallach Kogan	0.59
Reorientation total score	*Flexibility* total score	0.68

High and highly significant correlations were observed between the *Reorient-24* measure and IKEA AUT and total *Fluency* and *Flexibility* metrics, as shown in Table 6. A significant medium-sized inverse correlation of $r = -0.38$, $p < 0.04$ was observed between participants' NFC score and their reorientation-24 score. That is, the higher their NFC, the less likely participants were to either mentally reorient objects, or use the given object reorientation to identify uses for the given IKEA object stimuli. The higher their NFC, the more participants tended to give answers using the known default object orientation, and thus be affected by functional fixedness.

Table 6. Correlations between *Reorient-24* and other factors

Factor 1	Factor 2	r	p <
Reorient-24 IKEA AUT	NFC	-0.38	0.04
Reorient-24 IKEA AUT	*Fluency* IKEA AUT	0.71	0.001
Reorient-24 IKEA AUT	*Fluency total*	0.60	0.001
Reorient-24 IKEA AUT	*Flexibility* IKEA AUT	0.72	0.001
Reorient-24 IKEA AUT	*Flexibility total*	0.60	0.001

3.6.2 Creativity metrics correlation

Consistency of measurement was checked between the two creativity tests: 1) AUT using IKEA objects as visual stimuli in different orientations and 2) Wallach Kogan (WK) in its classical form, keeping the pattern stimuli in the same default orientation.

High correlations of high significance were observed both between *Fluency* scores in IKEA objects AUT and WK pattern meanings test, and between *Flexibility* scores in the IKEA objects AUT and the WK pattern meanings test, as shown in Table 7. Thus, the higher the participants scored on *Fluency* in the IKEA objects AUT, the higher they also scored on the *Fluency* in WK pattern meanings test. Similarly, the higher the participants scored on *Flexibility* in the IKEA objects AUT, the higher they also scored on *Flexibility* in the WK pattern meanings test.

Table 7. Correlations between factors, all $p < 0.001$

Factor 1	Factor 2	r
Fluency IKEA AUT	*Fluency* Wallach Kogan	0.52
Flexibility IKEA AUT	*Flexibility* Wallach Kogan	0.64

No significant correlations were observed between either *Reorientation* score in the IKEA objects AUT and the *Reorientation* score in the WK pattern meanings test.

3.6.3 Multiplicity and creativity metrics

Object *multiplicity* use measured whether participants explicitly made use of the multiple objects in three IKEA stimuli (O3, O8, O11). To rate an answer as using the *multiplicity* aspect, it was not enough that the plural of the object was mentioned, but for at least two instances of the object to have a use in the answer. For example, responses describing that the two *magazine files* can be used as *shoes* required the explicit use of both *magazine files*, i.e., to have a pair of *shoes* and be able to walk.

A significant medium-size correlation was observed between *multiplicity* score and IKEA objects AUT *Fluency*, as shown in Table 8. That is, participants using object *multiplicity* more also had higher *Fluency* scores. A significant medium-size correlation was also observed between *multiplicity* score and IKEA objects AUT *Flexibility* score. No significant correlations were observed between the *multiplicity* score and the *Fluency* nor *Flexibility* scores for the WK pattern meanings.

Table 8. Correlations between factors, all $p < 0.02$

Factor 1	Factor 2	r
Multiplicity score	IKEA AUT *Fluency*	0.43
Multiplicity score	IKEA AUT *Flexibility*	0.43

3.6.4 Creativity self-assessment and creativity evaluation

Participants self-assessed their creativity on a 5-point scale. Correlations were calculated between participants' self assessment of creativity and *Fluency* scores on the IKEA objects AUT, WK pattern meaning stimuli, and performance on the two combined. Table 9 shows these correlations, and that the higher participants self-assessed their creativity, the higher their *Fluency* scores. Also calculated are correlations between participants' self assessment of creativity and *Flexibility* scores on the IKEA objects AUT, WK pattern meaning stimuli, and performance on the two combined. Table 9 shows these correlations, and that the higher participants self-assessed their creativity, the higher their *Flexibility* scores.

Table 9. Correlations b/w self-assessed creativity and metrics

Creativity metric	r	p
Fluency IKEA AUT	0.48	$p < 0.01$
Fluency Wallach Kogan	0.42	$p < 0.02$
Fluency total score	0.51	$p < 0.01$
Flexibility IKEA AUT	0.50	$p < 0.01$
Flexibility Wallach Kogan	0.38	$p < 0.03$
Flexibility total score	0.48	$p < 0.01$

4. CREATIVE STRATEGIES FURTHER EXPLORED

This section further explores participants' responses, starting with phenomena that have implications for task evaluation. Next discussed are creative strategies participants used that may help overcome functional fixedness.

4.1 Observations with implication for task evaluation

One cannot analyze without context, participant responses, as they are likely influenced by the participant's previous ideas, and also by the participant's various domains of interest.

4.1.1 Previous uses

The first point is simple. For example, participant P90056 identified for two objects, O10 and later O8, with an intervening object between them, the possible use as a *sand mold*. Similarly, participant P81649 proposed that O7 can be used as a *podium to put laptop on*, and subsequently the same for O5. For both WK1 and WK3, participant P63514 identified the use *template for a kid's sketchbook*. Consistent with fixation research (Linsey et al. 2010, 2011), already triggered object uses may act as strong, activated associations when considering other, similar objects.

4.1.2 Semantic domain reuse

The same could be true for semantic domain. For example, once an initial instance activates the domain of *hats* (or generally things to put on one's head), this may lead to further examples in the same semantic domain. This is the case even if such things are not mentioned in abstract form, as an entire semantic domain. For example, participant P72018 first named *hat* as a potential use for O8 (plastic bowls), and then named other uses for subsequent stimuli that involve placement on one's head and face. These include *warrior helmet* and *voodoo mask* for O11 (storage box), and then *hat* and *crown* for O9 (gold bowl).

Whether it is (i) the semantic domain of hats that is triggered, (ii) a more general association with objects to put on one's face or (iii) heads and faces in general, it is hard to say. However, the possibility of the latter, over the former, is supported by another use the participant identified, this time in the context of WK4: *hair + one eye*. Note that this response is unique, i.e., no other participant identified it.

4.1.3. Domain flexibility across items

Another factor that can only be observed in the context of previous responses involves participants' domains of interest.

Flexibility is usually measured as a function of how many semantic domains the participant crosses when providing responses in the AUT. As described above, for a *brick*, if a participant offers both *paperweight* and *to press the newspaper with*, the resulting *Fluency* score is 2, and the *Flexibility* score is 1 (even if the responses are not issued one right after the other).

However, a deeper examination of responses for the IKEA AUT revealed that domain may deeply influence some participants. For example, participant P77829 appeared preoccupied with the sports domain, proposing the following sports-related (S) and physical activity and games (PAG) uses:

• O6 (toilet roll holder): *A pull-up fitness device* (S);
• O10 (storage box): *Hiding spot for children* (PAG);
• O4 (drum nightstand): *Sport (lifting exercise)* (S);
• O3 (toilet brushes): *Hitting someone* (PAG);
• O7 (TV stand): *Paintball protection shield* (PAG);
• O5 (coffee table): *Pull-ups; Push-ups* (S);
• O12 (glass vase): *As a weapon* (PAG);
• O8 (plastic bowls): *Shell game* (PAG);
• WK3: *A scratch for a game; (sticks put in the door)* (PAG);

P53249 focused on a domain involving musical instruments, in particular drumming, proposing the following uses:

• O4 (drum nightstand): *To drum on;*
• O11 (magazine files): *To drum on;*
• O7 (TV stand): *To tap dance on (I've seen something like this on the stage in a jazz concert);*
• O3 (toilet brushes): *To drum with (kind of like brushes used by drummers);*
• O2 (glass domes): *With a little iron spoon or something these could be used to play different notes, especially if they are filled with something (sand or something) to different degrees.*
• O12 (glass vase): *Turned upside down with water in different amounts can demonstrate changes in pitch;*

The same participant (P53249) was also preoccupied with the building of educational and children-related materials, e.g.,

• O4 (drum nightstand): *Children can roll it (in play);*
• O10 (storage box): *To bathe a baby;*
• O5 (coffee table): *Thinking of those "legs" as "ropes" it could be used as a swing;*
• O11 (magazine files): *They can be combined together and made into a box that you can peer into (through the holes) in some kind of children's guess what's inside game;*
• O12 (glass vase): *There's an interesting demonstration to engage students to think about combustion that could involve this as a jar that comes down to enclose a lit candle or two;*
• WK2: *Schema of the front of a radio with dials;*
• WK1: *Schema of gas particles moving in container with a partial barrier between parts of the container.*

The previously mentioned musical uses of O2 and O12 could also be included in the educational domain.

Similarly, P77142 often mentions machines and tools (M/T), designs and schematics (D/S), and (creating) object utility:

• O11(magazine files): *To raise smaller people* (M/T);
• O9 (gold bowl): *Kitchen aid* (M/T);
• O8 (plastic bowls): *Protection for table and chair feet* (D/S), *bird feed* (D/S);
• O10 (storage box): *Feed horses* (D/S);
• O12 (glass vase): *Magnifier* (M/T);
• O4 (drum nightstand): *Store rope* (M/T), *trap for snakes* (D/S);
• O1 (roller blind): *Project films or computer output* (M/T);
• O3 (toilet brushes): *Catch small animals in water* (D/S);
• O2 (glass domes): *Control glass for operating machine* (M/T);
• O6 (toilet roll holder): *Protection guide for machine* (M/T);
• WK4: *Tool for cutting* (M/T), *guidance to people* (M/T);
• WK3: *Tool for cutting, tool for orienting lines* (M/T);
• WK1*: Guidance* (D/S);
• WK2: *Tool for cutting, tool for kitchen* (M/T), *guidance for sitting in a room* (D/S).

Since no information on employment or hobby was collected, it is difficult to determine whether the observed domains of influence relate to participants' work or hobbies. However, with respect to the rating of responses, domains of expertise may add an extra flexibility dimension on all or most of participants' responses. In naming uses for each object, participants are likely to also identify responses related to their domain of interest, thus increasing their overall flexibility score. However, it is unclear whether this influence should be considered otherwise, as remaining in one's domain of expertise can be considered a measure of functional fixedness.

Clearly, it would be difficult to control for objects participants have encountered, including objects in their domains of expertise. This would be necessary to identify novel responses based solely on process, i.e., the capacity to identify such novel responses independent of existing knowledge. The process itself would be intrinsically related to knowledge, and may involve navigating to the right piece of information in knowledge. Therefore, a larger knowledge base may provide both the advantage of more possible answers to be found or constructed, as well as more territory to search. Computational metrics for this are still in discussion (Olteţeanu 2015b). Of interest for future work, Viswanathan & Linsey (2013) warn of the different effect of defixation materials on experts versus novices.

4.1.4 Elaboration versus abstraction

The participants differed in their degree of elaboration. For example, P69579, a participant with high elaboration tendencies, proposes for O2 (glass domes) uses including *keep different cheeses fresh/airproof* and *paint glass black and use for magician's trick hiding a ball under one of them and audience guesses where*. High-elaboration responses also occurred for the Wallach Kogan stimuli, e.g., WK2 is interpreted as the *top part of a mirror in a VIP dressing room with light bulbs*. Some high elaborations pertain to the use of the object, i.e., magic trick example, while other types detail how various parts of the stimulus map to parts of objects, i.e., the VIP mirror example.

Such high elaboration examples contrast with some participants' much less detailed responses. For example, for the same O2 (glass domes), P85253 offers the same use, *storing cheese*, but without the elaboration, and continued to offer 1 or 2 word answers for most of the subsequent objects.

P71017 especially tended towards abstraction instead of elaboration, where most responses were one or two words, and many reflect abstract categories. Example responses for O2 (glass domes) were: *decoration, storage, transport*.

Qualitatively, the elaboration level appeared to reflect the response style of the participant, rather than apply to particular answers, although not all responses given by high-elaboration participants are highly elaborate. A possible quantitative measure of elaboration that does not require human rating is to simply count the average number of words per object use.

4.1.5 Flexibility versus projection jumps

Another question is whether it is different uses that should be counted in the *Flexibility* metric or different projections of the existing object into other possible objects. For example, P37641 offers for O7 (TV stand) the following: *Used like a bench, to sit on, lie on or make sports with it.* While these represent different uses, it is clear that all three are related to perceiving the TV stand as a bench. Thus counting uses would yield a *Flexibility* score of 3, while counting (presupposed) projected objects would yield a *Flexibility* score of 1. If re-representing the object as other objects helps participants identify other uses, this metric may require modification. Or, a new metric could be developed to measure how projection jumps to other objects helped identify new uses. Such a metric would have computational comparability to existing systems capable of answering the AUT through this process, like the one by Olteţeanu & Falomir (2016).

Of relevance, Johnson et al. (2016) proposed a new novelty metric that extends Shah et al.'s (2003) metrics to improve abstract-idea evaluation, and tested it on participants' textual lists of ideas for how to solve general day-to-day problems.

4.2 Observed strategies that may reduce functional fixedness

Strategies that participants used to reduce functional fixedness include: multiple object reorientations; destroying and disassembling objects vs. adding other objects or parts; generalization and transfer; and association chains. Some of the strategies may loosely be described by SCAMPER, an acronym corresponding to Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse. However, at no point were participants introduced to SCAMPER, nor was it likely the given participants were familiar with SCAMPER. Moreno et al. (2016) found that SCAMPER increases the quantity of novel ideas. The universality of these strategies suggests they could be developed into heuristics, guidelines, or principles (Fu et al. 2016).

4.2.1 Multiple object reorientations and NFC

Some participants performed multiple object reorientations when identifying uses. For example, participant P26201, given O1 (*roller blind)* at 90°, proposed the following:

- *Making sushi;*
- *Sun protection;*
- *As a fabric to build something new;*
- *As a painting canvas;*
- *To divide rooms;*
- *To close a cupboard.*

To *make sushi*, the *roller blind* must be (smaller and) set on a table on a different orientation (rotation about a horizontal axis) from the default position (and any of the other orientations provided, which are created using rotations about a vertical axis). Using the object as *a painting canvas* implies an approx. 45° rotation about a horizontal axis. Using the stimulus object *to divide rooms* may require rotations about another horizontal axis.

Another example involves P69579, who named the following 11 uses (a high) for O12 (a glass vase) at 180°:

- *flower vase;*
- *lamp shade;*
- *glass knife (if broke at edges);*
- *greenhouse;*

- *container for candle*
- *wind protection or device to extinguish candle if used upside down;*
- *weight for gym exercises;*
- *hammer (if none at hand);*
- *table dust bin;*
- *ash tray;*
- *fly trap.*

The vase is thus reoriented several times to allow for the various uses. For example, *flower vase* implies returning the object to the default position and use, after which an 180° rotation yields the *lamp shade*. This orientation is likely maintained for the *greenhouse*. Next, the object is likely rotated back to default to become a *container for candle*, and another 180° for *wind protection or, device to extinguish candle*. A possible 90° rotation from the default follows to yield the use *weight for gym exercises*; this orientation is likely maintained for the *hammer*. The *table dust bin* and *ash tray* return the object to default orientation, while the *fly trap* may require a 180° rotation.

P67244 also showed a propensity for multiple reorientations. For example, O1 (roller blind, presented at 180°) was seen as a *curtain, retractable trampoline and retractable board*. O10 (storage box, 180°) elicited the responses: *bath, swimming pool, lid, cake pan, Lego, switch*. This reorientation tendency also extended to WK3, with elicited responses: *flying missiles, draft of urbanistic plan, aligned pencils, gates,* and *dead trees*.

Some participants not only rotated objects about the different axes (or took perspectives around it that would imply that rotation), but also took embodied first-person perspectives explicitly. For example, P72018 offered the following for O9 (gold bowl): *hat, crown, empty pockets, breast jewelry*.

As expected, presenting objects in rotated orientations may suggest to participants the strategy of re-orientation. However, this study showed a concrete NFC-based difference in how individuals use reorientation, even when the stimulus object is presented as reoriented, when identifying uses. Many high-NFC individuals only identified the object in the default orientation, and produced uses in this orientation, despite it being presented in a reorientation. For example, although a bowl is presented as inverted, rather than identify possible uses in this new orientation, e.g., cover, some high-NFC participants still only identified uses associated with bowls in their default orientation, e.g., to contain, serve or use to eat. An individual's NFC thus appears to be a good predictor of how much participants recognize reorientation as a cue in identifying product uses.

4.2.2 Destroying and disassembling objects

To achieve various new uses, participants sometimes destroy or disassemble the given objects. P63514 suggested regarding O5 (coffee table): *Take away the stands and you have a solid frame for gardening as terrace cultivation*.

P69579 offered the below uses that presuppose disassembly:
• O12 (glass vase): *Glass knife (if broke at edges)*;
• O1 (roller blind): *Jacket (if textile is cut and sewn into shape)* and *display for earrings (pierced through canvas).*

Other uses P69579 proposed imply the possibility of breakage: O7 (TV stand): *A karate practice device*.

P71017 seemed very focused on *recycling,* proposing for:
• O11 (magazine files): *Recycling of wood*;
• O10 (a storage box): *Recycling of plastics;*
• O9 (a gold bowl): *Melting*.

Destroying and disassembling could be generalized as a strategy to limit functional fixedness. In insight problems involving objects, many participants refrain from breaking objects, especially if a reassembly option is not perceived. However, an openness towards disassembly, far from being destructive in this case, can yield opportunities for new objects and object parts. Sometimes just thinking about object parts and the opportunity to replace those parts with others is enough of a *disassembly move* to allow the participant to identify alternative uses. For example, P53249 offers for O5 (coffee table): *Thinking of those "legs" as "ropes" it could be used as a swing*.

4.2.3 Adding objects and using given object as part of object

The given object stimulus is sometimes conferred new uses as part of a larger object. For example, P63514 responds regarding O5 (coffee table): *One level of a multi-level shelf (if stacked) to store away many different things,* and *solid stair steps for interior design*. O5 is thus seen as a part of a multi-shelf unit and a multi-step staircase. On a related theme, P69579 proposes for O11 (magazine files) the use *steps to reach up a shelf.*

Sometimes object *multiplicity* enables new uses, e.g., P53249 responds for O11 (magazine files): *They can be combined together and made into a box that you can peer into (through the holes) in some kind of children's 'guess what's inside' game*.

4.2.4 Generalization and transfer

Some participants were observed to use *generalization* as an interesting creative strategy, which can be characterized as follows. A participant first identifies a use (that is qualitatively more novel than the others), and then generalizes this use to an entire semantic domain of objects that are in some way similar.

Related to this strategy, but involving fewer objects in the second step, *transfer* implies mapping a novel use the participant has just named to an object or set of objects which is somehow similar. An example is *transferring* a use from *tables* to *chairs* (or between different types of tables), rather than *generalizing* from *tables* to *furniture.* Transfer involves both the first and second use being part of a larger semantic category, or the second item being in a neighboring semantic category. Transfer differs from generalizing upwards to a more inclusive category, and refers to assigning the same use to other objects that share a more inclusive category, or with which there is some semantic overlap.

Sometimes, both strategies, transfer and generalization are applied in the uses a participant identifies for the same object. For example, P63514 uses one or both strategies when coming up with answers for at least 7 of the set of 12 objects. In the order of answering (reflecting the random ordering of the objects), below are the 7 objects that involve one or both of the generalization (G) and transfer (T) strategies. Note that only responses containing G and/or T are below.

• O6 (toilet roll holder): *In the bathroom; any kind of consumption material kept on roll [. . .];* (G)
• O3 (toilet brushes): *Cleaning of vases and similar tube-shaped object;* (G)
• O10 (storage box): *Storage container for liquids, solids, etc.*(T)
• O4 (drum nightstand): *Tea-table; lunch table;* (T)
• O7 (TV stand): *Table to be placed on a couch's arm rest; table to be placed on any softer surface with the width of the u-shaped acrylic glass object;* (G)
• O9 (gold bowl): *Salad bowl; fruit bowl; nice storage object;* (T)+(G)
• O12 (glass vase): *Flower vase; place to arrange artificial flowers and plants.* (T)

In the above, the similarity of type between the stimulus and named objects varies in kind. For O6, this similarity refers to consumption materials which can be kept on a roll, for O3 the similarity refers to the tubular shape of the objects that can be cleaned; for O4, the similarity is implicit as transfer is done between items belonging to the same larger semantic category.

4.2.5 Association chains

Associative processes are considered a valuable measure of creativity (Mednick & Mednick 1971). Although explicit in neither the AUT nor its measurement, cognitive processes of association may still be at play for participants providing responses (Oltețeanu & Falomir 2016).

For example, P77829 offers for O10 (storage box) the responses: *Bath tub*, *Umbrella* and *Rain barrel*. From *bath tub* to *umbrella*, a possible association is based on water being contained in a bath tub, to the umbrella being used for protection from water. Combining the triggered concept of *rain* and the main storage function of O10 may have led to the *rain barrel*.

P69579 sometimes offered two responses with a forward slash for O12 (glass vase), implying a relationship between the following ideas: *container for candle / wind protection or device to extinguish candle if used upside down* and *table dust bin/ash tray*. The association chain initially revolved around the *candle, protecting and extinguishing*. Subsequent associations may be through *fire* and the resulting ash.

4.2.6 Ambiguity and alteration of material and size

Different types of *ambiguity* seemed to have a special role in participants' responses. *Ambiguity of material* is probably what allows answers like the ones given by P81649 to O1 (roller blind) at 90°: *door, presentation canvas, paper for writing like Egypt(ians)*. These answers presuppose or ascribe different materials to the stimulus object, e.g., *wood*, *plastic* and *paper*.

The influence of *size ambiguity* was observed when participants proposed uses which presuppose the different sizes. Sometimes, this ambiguity of size was directly expressed. For example, P63514 responds, to O10 (storage box): *depending on the real size of the object, cap to protect joints, storage container for liquids, solids etc.; basin for bathing; one-step-stand for household or small repair works*. P74381 responds for O5 (coffee table): *Table, depending on its height, as dining table or coffee table*.

Participants also changed the size of the object, e.g., P72018 identified for O4 (drum nightstand): *music instrument; seat; wheel; amulet; egg timer; bow tie*. Obvious size changes occur between uses as a *music instrument, seat or wheel* to uses as an *amulet, egg timer or bow tie*.

5. DISCUSSION AND FUTURE WORK

The high correlations of high significance between the AUT using concrete, and some purposely ambiguous, IKEA objects and the WK pattern meanings test, support the high likelihood that the two measured a coherent factor in creative performance.

High and highly significant correlations were also observed between creativity metrics *fluency* and *flexibility* and both *reorientation* scores. These correlations suggest that participants who tend to perform reorientations, are also more likely to come up with more uses and more abstract pattern interpretations. Furthermore, a medium correlation between NFC and tendency to reorient suggests individual differences in the ability to use cues to overcome functional fixedness.

In addition to reorientation, participants used other strategies that may help overcome functional fixedness. A qualitative analysis of these strategies led to various questions about how the AUT, a classical and seminal test, could be improved.

5.1 Possible new AUT evaluation measures

The *multiple object reorientation* cases show that some participants may be particularly fluent at reorienting given stimuli. Coupled with the correlation between reorientation and creativity, a future *fluency on reorientation* metric may be useful to explore how this influences creativity scores.

Semantic domain reuse suggests the value of collecting information on participants' professions and hobbies, although this might not completely elucidate related issues. The resulting AUT evaluation may require accounting for the semantic domain of each of the previous uses. Such accounting could potentially be accomplished using computational tools that reference existing ontologies or databases that index semantic relations, e.g., WordNet (https://wordnet.princeton.edu/).

To clarify whether elaborators are more, less, or simply differently productive from abstractors, an *elaboration* measure may be developed and used to compare different participants.

A new *flexibility* metric could be also developed to measure *projection jumps to other objects* in identifying new uses.

Of interest for future work, Pang & Seepersad (2016) studied the effect of empathic priming on crowd-sourced novice raters to evaluate design concepts, due to the time- and resource-intensive nature of concept evaluation. Fuge et al. (2013) introduced a probabilistic model that computes a family of repeatable creativity metrics trained on expert data.

5.2 Other strategies to overcome functional fixedness

Other strategies used by participants that may help overcome functional fixedness include: disassembling or destroying objects; adding other objects or parts; using the stimulus as part of an object; generalization and transfer; using association chains, and altering material and size. Some of these

strategies confirm process assumptions in computational systems solving the AUT (Olteţeanu & Falomir 2016).

The ability to predict an individual's responsiveness to cues has implications for interventions to accommodate such differences. Kruglanski & Fishman (2009) reported that NFC may be situationally manipulated, at least temporarily. Simple interventions could be tested initially. For example, especially high-NFC participants could be specifically instructed to use different orientations to identify different uses, or to imagine they are in an alien environment, in which the objects might look similar but serve different purposes.

Situational, rather than innate, NFC can also be manipulated using time pressure. Mayseless & Kruglanski (1987) studied situational or environmental NFC. Participants were asked to list as many hypotheses as possible for the identity of everyday objects shown in photographs that were enlarged to a point where the identity of the objects was unclear. Participants in the high-NFC condition were told that reaching firm decisions is an indication of general intelligence. Those in the low-NFC condition were told that correct visual identification is an indication of general intelligence. The number of hypotheses produced, from highest to lowest, came from the low-NFC group, a control group, and the high-NFC group. Related to the current study, a possible intervention is to more directly control the amount of time participants spend on a task, thus reducing the effects of individual self-imposed time pressure. Kudrowitz & Dippo (2014) noted that participants tend to identify only the most common uses in their first AUT responses.

Identifying the specific NFC statements that correlate to a tendency to incorporate reorientation may also lead to the development of interventions. The NFC statements that correlated the strongest with the tendency to incorporate reorientation during use identification have to do with uncertainty and unpredictability. Therefore, future work could examine whether interventions that encourage embracing uncertainty and unpredictability would affect the ability to incorporate creativity strategies.

ACKNOWLEDGMENTS

A-M Olteţeanu acknowledges the support of the German Research Foundation (DFG) for the Creative Cognitive Systems (CreaCogs) project OL 518/1-1. LH Shu acknowledges support of the Natural Sciences and Engineering Research Council of Canada (NSERC). Both authors acknowledge the support of the Hanse-Wissenschaftskolleg (HWK) in Delmenhorst, Germany.

REFERENCES

Batchelder WH, Alexander GE (2012) Insight problem solving: A critical examination of the possibility of formal theory. J Problem Solving 5/1:56-100.

Duncker K (1945) On problem solving. Psychological Monographs 58.

Fu K, Yang MC, Wood KL (2016) Design principles: Literature review, analysis, and future directions. Journal of Mechanical Design 138/10:101103.

Fuge M, Stroud J, Agogino A (2013) Automatically inferring metrics for design creativity. Proc. ASME IDETC2013-12620.

Guilford JP (1956) The structure of intellect. Psychological Bulletin 53/267.

Guilford JP (1967) The nature of human intelligence. McGraw-Hill.

Johnson TA, Cheeley A, Caldwell BW, Green M (2016) Comparison and extensions of novelty metrics for problem-solving tasks. Proc. ASME IDETC2016-60319.

Kudrowitz B, Dippo C (2014) When does a paper clip become a sundial? Exploring the progression of novelty in the alternative uses test. J Integrated Design and Process Science: Special Issue Applications and Theory of Computational Creativity. 17:4/3-18.

Kumar V, Mocko G (2016) Similarity of engineering design problems to enable reuse in design research experiments. Proc. ASME IDETC2016-60474.

Kruglanski A, Webster DKA (1993) Motivated resistance and openness to persuasion in the presence or absence of prior information. J personality and social psychology 65/5:861-876.

Kruglanski AW, Fishman S (2009) The need for cognitive closure. Handbook of Individual Differences in Social Behavior, 343-353. Guilford Press.

Lai SL, Shu LH (2014) Do-it-yourselfers as lead users for environmentally conscious behavior. 21st CIRP Conf. Life Cycle Engineering, Procedia CIRP 15C/431-436.

Lai SL, Shu LH (2017) Individual differences in tendency for design fixation. Proc. Design Computing & Cognition, Evanston, IL. 321-338.

Lenau TA, Keshwani S, Chakrabarti A, Ahmed-Kristensen S (2015) Biocards and level of abstraction. Proc. 20th ICED, 27-30 July, Milan, Italy, p177-186.

Linsey JS, Tseng I, Fu K, Cagan J, Wood KL, Schunn CD (2010) A study of design fixation, its mitigation and perception in design faculty. Journal of Mechanical Design 132/4:041003.

Linsey JS, Clauss EF, Kurtoglu T, Murphy JT, Wood KL, Markman AB (2011) An experimental study of group idea generation techniques: understanding the roles of idea representation and viewing methods. Journal of Mechanical Design 133/3:031008.

Mayseless O, Kruglanski AW (1987) What makes you so sure? Effects of epistemic motivations on judgmental confidence. Organizational Behavior and Human Decision Processes, 39(2): 162-183.

Marshall KS, Crawford R, Jensen D (2016) Analogy seeded mind-maps: A comparison of verbal and pictorial representation of analogies in the concept generation process. Proc. ASME IDETC2016-60100.

Mednick SA, Mednick M (1971) Remote associates test: Examiner's manual. Houghton Mifflin.

Moreno D, Blessing L, Yang M, Hernandez A, Wood KL (2016) Overcoming design fixation: Design-by-analogy studies and non-intuitive findings. AIEDAM 30/185-199.

Ohlsson S (1983) Restructuring revisited: I. Summary and critique of the Gestalt theory of problem solving. Scandinavian J Psychology 25/65-78.

Ohlsson S (1984) Restructuring revisited: II. An information processing theory of restructuring and insight. Scandinavian J Psychology 25/117-129.

Olteţeanu A-M (2015a) "Seeing as" and re-representation: Their relation to insight, creative problem-solving and types of creativity. Proc. Workshop Computational creativity, concept invention, and general intelligence. Publications of the Institute of Cognitive Science. Osnabrück 02-2015

Olteţeanu A-M (2015b) The input, coherence, generativity (ICG) factors. Towards a model of cognitive informativity measures for productive cognitive systems. Proc. Workshop Computational creativity, concept invention, and general intelligence. Institute of Cognitive Science. Osnabrück 02-2015.

Olteţeanu A-M, Falomir Z (2016) Object replacement and object composition in a creative cognitive system. Towards a computational solver of the Alternative Uses Test. Cognitive Systems Research 39/15-32.

Pang M, Seepersad C (2016) Crowd-sourcing the evaluation of design concepts with empathic priming. Proc. ASME IDETC2016-59417.

Plaks JP (2011) The Social Psychology of Motivation. Oxford University Press.

Shah JJ, Vargas-Hernandez N, Smith SM (2003) Metrics for measuring ideation effectiveness, Design Studies 24/111–113.

Toh C, Miller S (2016) The preferences for creativity scale (PCS): Identifying the underlying constructs of creative concept selection. Proc. ASME DETC2016-60414.

Viswanathan VK, Linsey JS (2013) Design fixation and its mitigation: A study on the role of expertise J Mechanical Design 135/5:051008.

Wallach MA, Kogan N (1965) Modes of thinking in young children: A study of the creativity-intelligence distinction. Holt Rinehart & Winston.

Webster D, Kruglanski A (1994) Individual differences in need for cognitive closure. J personality social psychology 67/6:1049-1062.

Zeki S (2004) The neurology of ambiguity. Consciousness and Cognition 13/1:173-196.

