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Learning in Product Development: Proposed Industry Experiment Using Reflective Prototyping

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Abstract

This article discusses the aspect of learning activities in product development by leveraging a strategy for capturing and transferring tacit knowledge through the extensive use of reflective prototyping. With the overall aim of finding new ways for organizations to learn faster, the theory from knowledge transfer is converted into a framework for using reflective and affirmative prototypes. Rooted in this framework, an automotive industry in-situ experimental setup for studying learning, continuous evaluation and knowledge generation in product development is proposed and discussed.

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Keywords: internal, reflective prototypes; prototyping; learning activities; design fixation; product development; experiment

1. Introduction

In this article, we investigate learning in product development, and the influence of concept representations at varying levels of affordance. Specifically, this includes exploring the role of reflective prototyping and design fixation. This article attempts to make two contributions to current literature.

Firstly, we review the relevant literature relating to creation and transfer of knowledge in product development. Furthermore, we review the role of several types of prototyping, design fixation and the concept of affordance in the context of product development.

Secondly, we propose an experimental setup on the role of concept representations in (early phase) product development. This experiment is intended for a R&D department of a global automotive tier 1/2 supplier.

The automotive industry is subject to steadily increasing demand for faster development cycles and higher quality products. Making mistakes leads to costly and time consuming rework. The product life cycles are generally in the order of five to ten years. Thus, changes have major implications on manufacturing process and planning.

In the early phases of automotive product development projects, the problems and concrete solutions are yet undefined. The main focus is on mapping possible directions for the R&D team. In this phase, quick learning cycles and continuous evaluation and selection of concepts are key. Poorly based decisions will lead to rework. In this regard, learning from past projects and managing the company's tacit and explicit knowledge is of high importance. The proposed experiment attempts to uncover some tangible aspects of how to approach these issues.

2. Theory: Learning Activities in Early Stage Product Development

In (1, 2), Simon lays a foundation for a "science of design". This is drawn up due to the recognition of the gap between professional knowledge and real world practice, applying methods from optimization within statistical theory; thus, laying the groundwork for a scientific approach to treating knowledge in design work.

This is criticized by Schön (3) for assuming technical rationality. He argues the focus should be on the extraction of requirements from real-world conditions, rather than the

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treatment of already well-formed ones. In (4), he further argues for reflective iteration as a learning tool, and elaborates on the difficulty of treating and directly creating explicit knowledge, without taking the tacit dimension into consideration.

2.1. SECI-model and Knowledge in Product Development

In (5), the theory of "Organizational Knowledge Creation" is proposed as the capability of a company as a whole to create new knowledge, as a result of studying the success of certain Japanese companies. This is further elaborated in (6) by establishing the SECI-model of dynamic knowledge transfer and creation. The SECI-model spirals through the stages of Socialization (tacit-to-tacit), Externalization (tacit-to-explicit), Combination (explicit-to-explicit) and Internalization (explicit-to-tacit). Through these stages, tacit and explicit knowledge are transferred alternately. To quote the original authors; "When tacit knowledge is made explicit, knowledge is crystallized". Thus, in a learning perspective, the most interesting stages of the SECI-model are those transferring explicit to tacit knowledge, or vice versa (i.e. Externalization and Internalization), when considering individuals. Additionally, transferring tacit to tacit knowledge (i.e. Socialization) is interesting when considering groups.

Another contribution of (5, 6) is the establishment of knowledge assets, which are Experiential (e.g. individual skills, interpersonal relationships), Conceptual (e.g. product concepts, images), Routine (organizational routines, culture) and Systemic (e.g. documents, databases, patents). The study performed in (7) concludes Conceptual knowledge assets to be the most efficient tool in facilitating Internalization and Externalization. They are defined as "knowledge articulated through images, symbols and language" (6), and although not specified in the definition, this can be understood to include sketches and physical models.

2.2. The Concept of Affordance

The concept of 'affordance', first introduced by Gibson (8, 9), describes the relation between an object and the actions that an animal could perform as a result of this object's properties. This was slightly modified by Norman (10), who stated that "the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used". The latter definition has gained major traction within certain product design communities. Despite some confusion around the use (and misuse) of the term in certain product design communities (11), the term is most often used as for describing physical objects and their meanings.

When using the term prototype affordance to describe both physical attributes and meanings of a product in engineering design, it is useful to make the distinction between prototype affordance and semantics (12). We differentiate between object meaning in prototype

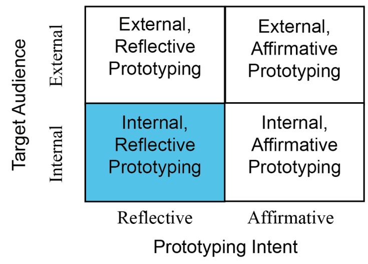

Figure 1 - A model of four prototyping categories (14).

affordance and semantics, as affordances cover all perceivable information provided by the object itself. On the other hand, the semantics cover perceived (and user-processed) product meanings provided by the object and context. Hence, prototype affordance – in our setting – is all the physical properties and all information embodied in the given object, before any interpretation (i.e. in SECI-model; internalization) is done by the participant.

2.3. The Role of Prototypes in Learning Activities

In (13), prototypes are defined as "an approximation of the product along one or more dimensions of interest", and prototyping is defined as "the process of developing such an approximation of the product".

For the purpose of distinguishing between prototyping activities by their function, the authors propose categories in (14), dividing prototypes by the prototyping intent (reflective or affirmative) and the target audience (internal or external). The referenced work is focusing on physical prototypes, while this paper is focusing on the prototyping activity. However, we argue that the categories are transferable (Figure 1).

External, affirmative prototyping is typically used for approximating a nearly finished model, and may be termed alpha or beta prototypes (15). These prototypes are highly detailed, and may be made for external validation (e.g. certification test for customers etc.), showcasing, or in-depth customer interaction.

Internal, affirmative prototyping is intended for function, reliability and feasibility testing. Examples include subsystems, fatigue testing of separate parts, or project milestones as a means of measuring the progress. Despite the high fidelity this prototyping is rarely done for public display.

External, reflective prototyping is building models for feedback from external sources. The responses and reactions are recorded, and the user interaction is carefully observed for further improving the concepts.

Internal, reflective prototyping is a learning activity. It is applied by product development teams for learning and conceptualizing ideas. This category of prototyping is exploring, understanding and experimenting with functionalities essential for the final product's success. The low-fidelity nature of the prototypes means there is less investment in the idea for the originator, and there is a relatively low threshold for criticism, change, or discarding.

Examples of internal, reflective prototyping are sketching and low-fidelity physical prototyping. This has been used in several industry cases (14).

Former studies have shown interaction with physical prototypes during idea generation to yield better performing designs than those only interacting with sketches (16). In addition, physical models contribute the most to the acquisition of knowledge (i.e. learning) (17). However, sketching during idea generation is argued in (18) to be the quickest way for designers to influence each other's mental models.

Both low-fidelity physical prototyping and sketching fall under the category of internal reflective prototyping. Thus they illuminate the distinction between high affordance internal, reflective prototyping (i.e. physical modelling) and low affordance internal, reflective prototyping (i.e. sketching).

2.4. Design fixation in requirements elicitation

In (19), design fixation is defined as "a blind adherence to a set of ideas or concepts limiting the output of conceptual design". That is, fixation on examples, and the inhibiting effect it has on further idea creation. Several studies have been made to examine attainable measures for minimizing design fixation. Some suggested solutions to design fixation are incubation (20) and design-by-analogy (21). Function trees have been shown to yield less design fixation than sketching (22), and what has been coined "the preference effect" shows that people fixate on their own ideas at the expense of those shared by others (23).

With respect to requirements elicitation, we apply terminology from the tacit knowledge framework (24, 25), using the terms "knowns" and "unknowns". The reflective prototyping categories aim at exploration, thus uncovering the unknown problems/concepts – the 'unknown unknowns' (i.e. non-articulated problems with unknown solutions). Coming from this perspective, we argue that known problems/concepts are best discovered analytically, while unknown problems/concepts are best solved exploratory.

A positive effect of testing physical models in mitigation of design fixation has been shown in (26). The studies made in (28, 29), both done with industrial design students in groups, conclude sketching to be the best representation aid for originality in the designs made during idea generation, while physical modelling yields more functional designs. Thus, indicating there is more design fixation involved when doing physical modelling than sketching, and that testing the physical models reduces fixation.

The role of the "sunk cost effect" (29) explains this by pointing out the investment in the design made by the designer, i.e. the more time and effort put into a concept, the less likely a designer is to discard it. With respect to the "sunk cost effect" one would assume a correlation between affordance and design fixation. However, studies have been done comparing sketching (i.e. low affordance) and physical modelling (i.e. high affordance), with no sign of this correlation (16, 30). A possible explanation is raised in (30).

	EVALUATION ROUND		ITERATIVE DESIGN ROUND	
TIME	t = 15 min.		t = 30 min.	
AFFORDANCE	HIGH	VS. LOW	HIGH	VS. LOW
TOOLS USED	PRE-MADE PHYSICAL PROTOTYPES	PRE-MADE ISOMETRIC DRAWINGS	PROTOTYPING BUILDING KIT	SKETCHING EQUIPMENT
DESIGN TASK	EVALUATE CONCEPTS AND WEIGH ATTRIBUTES		ITERATE AND IMPROVE CONCEPTS	
HYPOTHESES	PROBLEM AND CONCEPT UNDERSTANDING		DESIGN FIXATION	LEARNING ACTIVITY

Figure 2 – Proposed experimental scheme.

The "sunk cost effect" suggests designers are more devoted when a significant amount of effort is put into a design. The controlled studies (16, 30) had shorter time for idea generation and building than the studies done by observing real teams (27, 28), and consequently may not have had time to be sufficiently invested.

Further, the controlled study in (16) is evaluating the designs of groups and nominal groups (i.e. results from individuals completing the experiment put together in nominal groups after completion). The study concludes the ordinary groups to fixate more than the nominal groups. Thus, indicating that designers in groups – while able to build upon each other's ideas and creating more functional concepts – also fixate more.

2.5. Hypotheses

Grounded in this theory, and with the aim of exploring the impact of altering prototyping affordances during early stage engineering design activities, we propose three hypotheses; the Problem and Concept Understanding Hypothesis, the Design Fixation Hypothesis and the Learning Activity Hypothesis.

2.5.1. Problem and Concept Understanding Hypothesis

Based on the framework around internal, reflective prototyping, we aim to gain a better understanding of prototype affordance and how this affects the participants' ability to evaluate concepts. Hence, the hypothesis is:

Interaction with high affordance prototypes will lead to greater problem and concept understanding (during concept evaluation) than interaction with low affordance prototypes.

2.5.2. Design Fixation Hypothesis

Further, based on the framework around internal, reflective prototyping and design fixation, we aim to gain a better understanding of how prototype affordance affects the participants' fixation when designing. This translates into:

Prototyping with high levels of affordance will lead to more fixation (when designing) than prototyping with low levels of affordance.

2.5.3. Learning Activity Hypothesis

Lastly, based on the framework around internal, reflective prototyping as a learning activity, we aim to gain a better understanding of how prototype affordance affects the participants' learning outcome when designing:

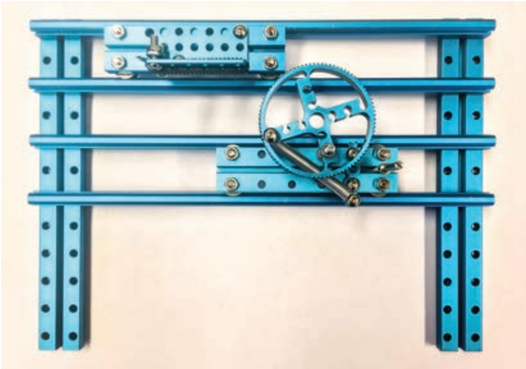

Figure 3 - Example of a high affordance prototype.

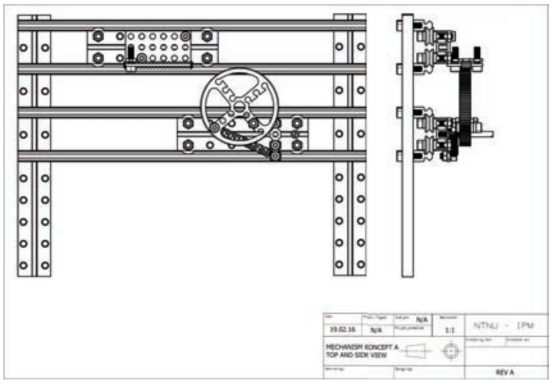

Figure 4 - Example of a low affordance prototype.

Prototyping with high levels of affordance will lead to higher quality designs than prototyping with low levels of affordance.

3. Proposed Experimental Setup

The hypotheses stated in the previous section will be evaluated in a proposed design experiment (Figure 2). This section is devoted to elaborating said experiment. The evaluation of the hypotheses is divided into a two-part controlled experiment setup. All participants are randomly assigned to either of two conditions, also describing the kind of internal, reflective prototyping activity they will be using for the duration of the experiment: 'Low Affordance' and 'High Affordance'.

When starting the experiment, all participants are handed the initial problem definition. This problem definition is stated as a written text, together with a requirement specification and an illustration. As we are working with a global automotive tier 1/2 supplier, our initial problem definition is mechanical, and closely related to problems the participants might face in everyday engineering design activities.

As we are interested in the participants' problem and concept understanding, and their ability to utilize this understanding, the experiment consists of two subsequent tasks. The first task is to do a round of concept evaluation, where participants are asked to evaluate a number of pre-defined concepts, all trying to satisfy the initial problem requirements. This task is referred to as 'evaluation round'. The second task is to re-iterate a new and improved design, still based on the initial problem requirements. Lastly, the participants are asked to pick one concept, and finalize this for expert evaluation at the end of the second task. The second task is referred to as 'iterative design round'.

3.1. Participants

The experiment is intended for automotive engineers who are experienced in the field of product development. The participants are expected to be familiar with concept evaluation and generation. There will be a minimum of 12 participants per independent variable ($N \geq 24$). Prior to the experiment, experimental pilots have been run, with mechanical engineering students as pilot participants.

3.2. Tools, Equipment and Materials

All participants, regardless of group assignment, are given an identical copy of the initial problem definition. Each copy includes a written problem text, a specification stating the requirements of the designs, and an illustration of the problem. As the group conditions also describe the affordance of the internal, reflective prototyping equipment they will be using throughout the experiment, the two groups will be provided slightly different equipment in each round.

Prior to the experiment, four concepts have been made according to the initial problem definition, and these will be used in the evaluation round. All four concepts are represented by both low and high affordance prototypes. The high affordance prototypes (Figure 3) are physical models, made in a modular, aluminum building kit (MakeBlock^{TM}). All pre-made concepts are based on a mechanical test rig, which includes two linear rails and two mounting brackets – interfaces used in the design task. This rig is made from the same building set. The low affordance prototypes (Figure 4) are represented by multiple isometric drawings, which are drawn using the high affordance prototypes for reference.

During the evaluation round, all participants are asked to fill out a Pugh-diagram (i.e. evaluation matrix), containing pre-selected evaluation criteria. Normally, Pugh charts contains weighted categories, but as the aim of the evaluation round is to check both problem and concept understanding, this weighing is left blank for the participants to fill out. A short description on using the Pugh-diagram is provided along with the task description, though it is expected that all participants are familiar with the diagram prior to the experiment.

During the iterative design round, participants under the low affordance condition will be given lower affordance tools while iterating their new designs, here represented by standard sketching tools (i.e. squared paper, pen, pencil, ruler, eraser, protractor, compass). Conversely, participants under the high affordance condition will be given higher affordance tools, represented by the same anodized aluminum building kit as in the evaluation round. The participants under the high affordance condition are also allowed to use and interact with the high affordance prototypes for the duration of the experiment.

During the finalizing of the concepts in the iterative design round, all participants (regardless of group condition), will be handed the same tools, including a pre-made rig for testing the mechanical interface of the concepts. This way, both groups will use more time on assessing critical functionality of their designs.

To make the experiment as realistic as possible, the experiment area is set in a standard meeting room, with a centered medium-sized table and office chairs. The room is closed off to any persons not taking part in or running the experiment. Before each participant enters the experiment area, the room layout is reset, and all necessary tools and equipment are laid out on the table surface. The experimental area is equipped with video-cameras, as the participants will be filmed for the duration of the experiment. There is also a dedicated camera for filming the participants' final concept presentations after the iterative design round.

3.3. Proposed Experimental Procedure

Before starting the experiment, all participants are greeted and welcomed into a waiting area. Here, they are asked to fill out a consent form and told that further communication during the experiment will be provided in written text. The participant is given the initial problem definition handout, and is given five minutes to read and contemplate on the problem. When the participant is handed the initial problem definition, the experiment is considered as running, with only one participant at a time.

3.3.1. Evaluation Round

After the first five minutes of reading, the task description for the evaluation round is handed out, along with an empty pre-made Pugh-diagram for evaluating the different concepts. The pre-made concepts are thereby presented, with level of affordance according to group condition. Participants are given fifteen minutes for evaluating the pre-made concepts, after which they are asked to hand in the complete Pugh-diagram.

3.3.2. Iterative Design Round

Upon handing in the Pugh-diagram, each participant will be handed the task description for the iterative design round. In addition, each participant will get prototyping equipment according to their group condition. Each participant is given twenty minutes to improve and iterate a better design than the four previous concepts. After these 20 minutes, all participants (regardless of group condition) are handed a physical prototyping kit, and get instructions to finalize a conceptual prototype for evaluation. Finally, each concept is handed in for external evaluation. This is done by each participant getting to record a two-minute demonstration in a video-log format.

3.4. Proposed Metrics for Evaluation

In this section, we will cover the necessary steps in gathering metrics for evaluating the three stated hypotheses. This includes both definition and quantification of all variables. In this experiment, we are using three expert ratings, somewhat similar to what has been done in (16, 31).

3.4.1. Independent Variables

For all three hypotheses, the independent variable is prototyping affordance. As we do not intend to quantify this beyond stating that we are using high and low levels of affordance, this is a categorical variable, with two discrete conditions. Note that we differentiate between high/low affordance prototypes (i.e. objects) and high/low affordance prototyping (i.e. activities). However, the independent variable is the level of affordance being used, we view this as the same independent variable for all practical purposes.

3.4.2. Dependent Variables

For the problem and concept understanding hypothesis, we include two dependent variables; 'problem understanding' and 'concept understanding'. Both variables are measured by using an expert ranking system, getting three independent experts ranking the pre-made concepts in the same Pugh-diagram as the participants. The experts' ratings of weighted categories are used as a baseline for the 'problem understanding' variable, and the ratings of each specific concept is used as baselines for the 'concept understanding' variable. Each participant's deviation is compared to the experts' combined baseline, indicating the participant's level of (problem and concept) understanding. We argue that by observing this deviation, we can extrapolate whether or not the participants have sufficient understanding of each concept.

To test the design fixation hypothesis, the number of neutral and negative fixation features present, in each of the finalized conceptual prototypes (after the iterative design round), is identified by three independent experts. These neutral and negative fixation features are based on the pre-made concepts, thus giving a measure of how fixated the finalized conceptual prototypes are.

For the learning activity hypothesis, we are using 'quality of design' as the dependent variable. This variable is quantified by using the same independent expert ranking (i.e. using the same Pugh chart), and comparing the finalized conceptual prototype to the pre-made concept prototypes. Here, the 'quality of design' variable is defined as the deviation from the pre-made concepts, where positive deviation indicates better quality, and negative deviation indicates lower quality than the experiment baseline.

4. Discussing the Proposed Experiment

As this paper aims at proposing an experimental setup, we are aware of several limitations that may apply. We have chosen to focus our efforts on exploring how affordance will affect learning outcome. Therefore, we are using the same two group conditions for each of the rounds. One could argue that, to do a more thorough evaluation of the hypotheses, we could divide the groups after the evaluation round, and arrange participants from each condition into new conditions for the iterative design round. This has been avoided, mostly due to the experiment being aimed at a professional company setting. Therefore, the number of participants available is somewhat limited.

Also, one can argue that participants who are using the high affordance prototyping kit during the whole experiment have a major advantage when finalizing designs in the second round. We try to mitigate this effect by giving all participants a pre-assembled testing rig, making the gap between low and high affordance as small as possible.

We are dealing with professional participants from a real engineering design setting, and hence there will be an effect from pre-experiment biases, difference in experience and other considerations not taken into account.

5. Conclusion

In this paper, attempts have been made to understand learning and learning activities within product development (both individual and organizational), and the influence of the concept of affordance on learning outcome. With this in mind, roles of different prototyping categories have been presented, with emphasis on internal, reflective prototyping as a learning activity.

Furthermore, the article has proposed an experimental setup and procedure to test three hypotheses: a hypothesis on concept and problem understanding; a hypothesis on design fixation; and a hypothesis on learning activity outcome. A framework for evaluating said hypotheses is presented, complimented by some considerations on the limitations of this experiment. Initial piloting of the experiment has begun, and early piloting indicate that high affordance prototypes may lead to both more problem and concept understanding.

Ultimately, this experiment is intended for professional practitioners in engineering design, and we hope this will help understand the learning mechanisms of internal, reflective prototyping in a real-world setting.

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References

[1] A. H. Simon. Administrative behavior; a study of decision-making processes in administrative organization. Oxford, England: Macmillan; 1947. 259 p.
[2] Simon HA. The Sciences of the Artificial. MIT Press; 1996. 252 p.
[3] Schön D. Educating the Reflective Practitioner [Internet]. San Francisco: Josey-Bass Publishers. 1987 [cited 2016 Jan 30]. Available from: http://cumincad.scix.net/cgi-bin/works/Show?54c7
[4] Schön DA, Wiggins G. Kinds of seeing and their functions in designing. Des Stud. 1992 Apr;13(2):135–56.
[5] Nonaka I, Takeuchi H. The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation. Oxford University Press; 1995. 320 p.
[6] Nonaka I, Toyama R, Konno N. SECI, Ba and Leadership: a Unified Model of Dynamic Knowledge Creation. Long Range Plann. 2000 Feb 1;33(1):5–34.
[7] Chou S-W, He M-Y. Knowledge Management: The Distinctive Roles of Knowledge Assets in Facilitating Knowledge Creation. J Inf Sci. 2004 Apr 1;30(2):146–64.
[8] Shaw RE, Bransford J. Perceiving, acting, and knowing [Internet]. Lawrence Erlbaum Associates; 1977 [cited 2016 Feb 10]. Available from: http://www.trincoll.edu/~wmace/publications/Ask_inside.pdf
[9] Gibson JJ. The Ecological Approach to Visual Perception: Classic Edition. Psychology Press; 2014. 347 p.
[10] Norman DA. The psychology of everyday things. Basic books; 1988.
[11] Norman DA. Affordance, Conventions, and Design. interactions. 1999 Mai;6(3):38–43.
[12] You H, Chen K. Applications of affordance and semantics in product design. Des Stud. 2007 Jan;28(1):23–38.
[13] Ulrich KT, Eppinger SD. Concept selection. Prod Des Dev 5th Ed Phila McGraw-HillIrwin. 2012;1:145–61.
[14] Erichsen J, Pedersen A, Steinert M, Welo T. Using Prototypes to Leverage Knowledge in Product Development: Examples from the Automotive Industry. 2016 IEEE Int Symp Syst Eng ISSE.
[15] Otto KN, Wood KL. Product Evolution: A Reverse Engineering and Redesign Methodology. Res Eng Des. 1998 Dec;10(4):226–43.
[16] Youmans RJ. The effects of physical prototyping and group work on the reduction of design fixation. Des Stud. 2011 Mar;32(2):115–38.
[17] Kiriyama T, Yamamoto T. Strategic knowledge acquisition: a case study of learning through prototyping. Knowl-Based Syst. 1998 Desember;11(7–8):399–404.
[18] Goldschmidt G. To see eye to eye: the role of visual representations in building shared mental models in design teams. CoDesign. 2007;3(1):43–50.
[19] Jansson DG, Smith SM. Design fixation. Des Stud. 1991 Jan 1;12(1):3–11.
[20] Smith SM, Blankenship SE. Incubation and the Persistence of Fixation in Problem Solving. Am J Psychol. 1991;104(1):61–87.
[21] Moreno DP, Yang MC, Hernández AA, Linsey JS, Wood KL. A Step Beyond to Overcome Design Fixation: A Design-by-Analogy Approach. In: Gero JS, Hanna S, editors. Design Computing and Cognition '14 [Internet]. Springer International Publishing; 2015 [cited 2016 Feb 8]. p. 607–24. Available from: http://link.springer.com/chapter/10.1007/978-3-319-14956-1_34
[22] Atilola O, Tomko M, Linsey JS. The effects of representation on idea generation and design fixation: A study comparing sketches and function trees. Des Stud. 2016 Jan;42:110–36.
[23] Nikander JB, Liikkanen LA, Laakso M. The preference effect in design concept evaluation. Des Stud. 2014 Sep;35(5):473–99.
[24] Gervasi V, Gacitua R, Rouncefield M, Sawyer P, Kof L, Ma L, et al. Unpacking Tacit Knowledge for Requirements Engineering. In: Maalej W, Thurimella AK, editors. Managing Requirements Knowledge [Internet]. Springer Berlin Heidelberg; 2013 [cited 2016 Jan 28]. p. 23–47. Available from: http://link.springer.com/chapter/10.1007/978-3-642-34419-0_2
[25] Sutcliffe A, Sawyer P. Requirements elicitation: Towards the unknown unknowns. In: Requirements Engineering Conference (RE), 2013 21st IEEE International. 2013. p. 92–104.
[26] Viswanathan V, Atilola O, Esposito N, Linsey J. A study on the role of physical models in the mitigation of design fixation. J Eng Des. 2014 Mar 4;25(1-3):25–43.
[27] Vidal R, Mulet E, Gómez-Senent E. Effectiveness of the means of expression in creative problem-solving in design groups. J Eng Des. 2004;15(3):285–98.
[28] Acuna A, Sosa R. The Complementary Role of Representations in Design Creativity: Sketches and Models. In: Design Creativity 2010 [Internet]. Springer; 2011 [cited 2016 Feb 12]. p. 265–70. Available from: http://link.springer.com/chapter/10.1007/978-0-85729-224-7_34
[29] Viswanathan VK, Linsey JS. Role of Sunk Cost in Engineering Idea Generation: An Experimental Investigation. J Mech Des. 2013 Sep 18;135(12):121002–121002.
[30] Viswanathan VK, Linsey JS. Physical models and design thinking: a study of functionality, novelty and variety of ideas. J Mech Des. 2012;134(9):091004.
[31] Viswanathan VK, Linsey JS. Role of Sunk Cost in Engineering Idea Generation: An Experimental Investigation. J Mech Des. 2013 Sep 18;135(12):121002–121002.