Role of design representations on design creativity

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***Abstract*— This essay explores how different design representations influence creativity, focusing on sketches, which are immediate and open to reinterpretation, and function trees, which are purpose-oriented. While visual representations can induce fixation, function trees are found to enhance creativity. The analysis addresses how design examples and team collaboration can introduce biases, drawing on personal engineering and design experience. It also emphasizes the need for further research into how other types of representations and prior knowledge influence creativity.**

I. Introduction

There are different types of design representations, each with distinct characteristics and objectives. Whether used as examples or to convey information, they can hinder creativity and lead to fixation.

Some representations induce cognitive biases more than others. The contrast between visual and functional models is particularly significant, with attention given to the quantity and quality of ideas fostered by sketches vs. function trees.

The ability of these to inspire innovative concepts is analyzed within the framework of design sciences and personal experience, aiming to determine which representations are most likely to lead to fixation and exploring strategies to mitigate this effect.

II. Paper's content

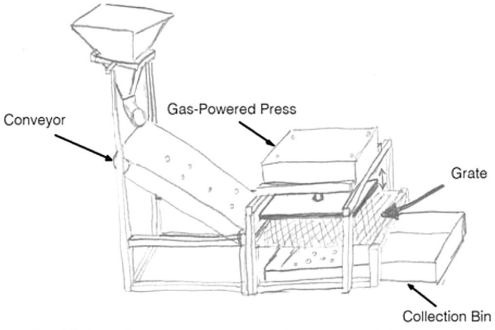
The effects of representation on idea generation and design fixation: a study comparing sketches and function trees [1] analyzes the role of design representations on design creativity and fixation. It examines how to both minimize cognitive bias and maximize ideation of variants.

Conceptual design, focused on idea generation, needs tools to communicate existing and new design ideas. Engineers often favor diagrammatic representations like sketches, or CAD in recent times, to avoid mentally demanding abstractions and clearly identify problems. Sketches, often accompanied by text, are proven to improve design quality and their inherent ambiguity fosters creativity and reinterpretation.

Function trees, on the other hand, abstract design requirements by alternating between functions (*what* the design does) and means (*how* it achieves these functions). This approach helps designers concentrate on functional abstractions rather than specific solutions.

While examples and external stimuli aid creativity, they may also constrain problem-solving. Studies have shown that sketches lead to fixation, a condition where designers become stuck with initial ideas. The paper investigated the hypothesis that function trees *defixate* and improve design quality by encouraging the exploration of alternative solutions within the concept space.

The experiment assigned participants a design task: a peanut sheller for developing countries. They were encouraged to provide many solutions and were supplied with an example (a *poor design*, using an unsustainable gas-powered press) in the form of a sketch (Figure 1), a function tree (Figure 2), or a combination of both. A control group did not receive materials.



Solution Description: This system uses a gas powered press to crush the peanut. The peanuts are pressed against the grate and the shells are broken. The grate separates the nuts from the broken shells; the nuts then fall into a collection bin.

Fig. 1: Sketch of example used [1]

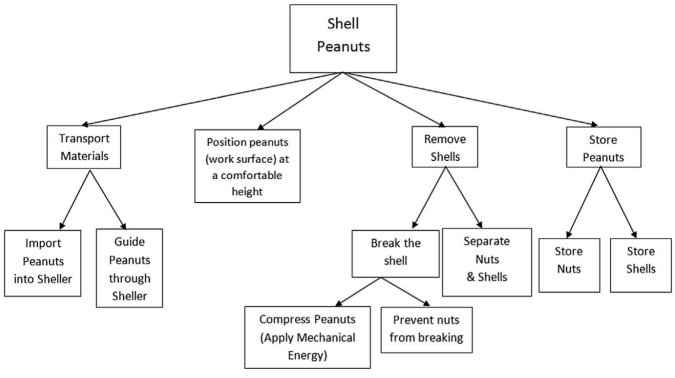


Fig. 2: Function tree of example used [1]

Design concepts were defined as individual solutions, and ideas as features addressing at least one function. Some creativity metrics were particularly interesting.

The *quantity of non-redundant ideas* was similar to the control group for the function tree but significantly lower

for the sketch. The combination of function tree and sketch did not differ from the control, meaning that sketches induce fixation, while function trees mitigate some of its aspects.

Similarly, the sketch condition led to more *repeated example features* compared to the control. Obviously, no difference was found between the function tree and the control groups. Instead, when both methods were combined there was a tendency towards increased fixation: designers might feel compelled to address functions with preexisting solutions, rather than exploring new ones.

The highest *quality* score in the function tree group suggests that this representation helps creativity. The other three conditions were similar, meaning sketches do not harm design quality and that combining both methods does not offer additional benefits.

Overall, function trees reduce fixation and boost creativity compared to sketches alone. However, their combination tends to reinforce fixation on example features while decreasing fixation on ideas.

III. Discussion of the paper's message

Design representations can significantly constrain creativity. They are essential for inspiration during early work stages and for team discussions. Since design is an iterative process [2] based on exchanging ideas and their representations, fixation on any of them can limit the exploration of alternatives.

Design is inherently a cultural and individual manifestation: past experiences, personal beliefs, and geographical and historical context create paradigms that are difficult to overcome. Even with open-mindedness, constant exposure to external data can lead to cognitive biases that limit creativity, thus highlighting the importance of conveying information in the most effective way.

Sketches offer several advantages not only for seeking inspiration, but also for developing concepts. They are rapidly made, do not need to be complete or precise, and can be easily modified by adding or emphasizing details [2]. However, sketches typically convey a specific solution, which can constrain the designer, requiring further abstraction from the particular case to general principles. Indeed, the more detailed the sketch, the less radical the outcome tends to be.

In other words, a sketch often focuses on *how* to meet requirements. Induction is essential for generating a whole class of ideas to address specific needs, and this process can anchor the mind to the specific case and lead to fixation.

Function trees focus instead on *what* the design should achieve, rather than its implementation. Functional abstractions facilitate the transition from Knowledge Space (*k-space*) to Concept Space (*c-space*), enabling exploration and design of novel solutions. Designers can approach problems from different angles in an unconstrained manner.

This methodology promotes idea reformulation and avoids fixation by enabling the development of different variants. It has been shown [3] that increasing the quantity of ideas tends to improve their quality. Consequently, function trees not only reduce fixation but also enhance design quality, while the presence of sketches complicates the development of alternative concepts.

However, it's important to distinguish between different aspects of fixation. Fixation on ideas is induced by sketches but mitigated by function trees. The fact that more ideas arise from their combination is due to the abstraction provided by functional representations, which partially deprives the example of its uniqueness.

Intuitively, combining diverse references should enhance creativity by increasing knowledge. At the same time, this also introduces cognitive bias and additional constraints. Fixation on example features is favored by using both sketches and function trees, resulting in less original ideas.

Function trees anticipate innovations more effectively than sketches. In modern design, where engineering solutions are often readily available, this approach prioritizes innovative concepts before addressing specific technical details, reducing technological fixation. By prioritizing functions rather than means, design becomes a catalyst for technical creativity.

IV. Personal experience and reflection

I have personally observed that visual representations in design can constrain creativity. Among them, sketches and drawings are likely the ones that leave more space for imagination, while CAD models or pictures are often more fixating. Being presented with fully developed solutions often biased me at a point where no other possibilities seemed better, or even possible.

I was once asked to design a tank bottom valve based on existing CAD drawings. Some variants had to be realized, potentially changing the original design but ensuring it could sustain a certain pressure differential and be manually closed at need.

Drawings and the working principles represented there were useful references, but exploring new concepts proved so challenging that the final design remained close to the original. Despite efforts to find new solutions, the initial design always felt like a safe place. If only the functions had been provided, rather than the detailed model, the mental effort required for change would have been lower.

However, the paper neglects the key distinction between creativity and improvisation. While avoiding real examples can reduce bias, relevant prior experience is crucial, and sketches and drawings are needed to mature in the field.

A solution is to be inspired by related systems. For instance, since I had limited knowledge of bottom tank valves, studying various hydraulic systems would have helped.

Currently, I am working with a team to design a robotic end-effector for pruning vineyards. The cutting mechanism is constrained by a robotic arm, whose characteristics are known: geometry, kinematics, and (low) gripping force. Functions have been listed, and sketches, drawings and photographs serve as inspirations. On the other hand, the combination of the two methodologies sometimes leads to fixation, similar to what the paper described.

Several functions need to be addressed, all of which fall under two main needs: cutting (which involves controlling precision, depth, size, and force) and sustaining the end-effector (which includes support, gripping, and stability).

Addressing the ones regarding cutting is also inspired by some visual representations. Alternatives can be explored by *defixating* from specific cutting tools like scissors, although they are featured in most example sketches. Focusing on the fundamental goal of removing branches, regardless of *how*, generates more ideas. However, some drawings suggest drilling as a viable alternative, thus designs tend to fixate on these examples.

None of the sketches address instead how to sustain the end-effector, which has led to several original and creative ideas for overcoming the limitations of the robotic arm's low gripping force.

Based on my experience, one of the main challenges of design representations in team settings is also conveying concepts and information to others without introducing bias. Detailed designs often lead to treating initial ideas as definitive, rather than iteratively seeking the optimal solution.

As a consequence, the modern tendency to immediately develop CAD models tends to impose one concept over the others. Rough sketches, or function trees in the early stages, are preferable. They focus on the purpose of ideas instead of their implementation, allowing for ambiguity and multiple interpretations that designers can leverage during the creative process.

However, digital tools have become the new frontier of engineering representations, replacing sketches even in the early conceptual phase. Designers' skills and aptitude have evolved to embrace this change, with CAD tools being a significant part of their education. It's likely that their combination with function trees will become increasingly present in the world of creativity.

V. Further investigation

Additional research could provide new insights into the role of design representations in creativity.

First, all participants in the experiment reported in the paper were from the same class and reasonably shared the same knowledge and aptitude. It would be interesting to test how different skill sets influence perceptions of sketches or function trees in terms of creativity.

Visual examples might lead to greater fixation for the least experts, while for the most skilled, used to abstraction and concept generation, the difference might be less noticeable. Those who lack experience completely may even struggle to produce new ideas when provided only with sketches, since in their mind technology and corresponding function are strictly intertwined. Combining both types of representations could also benefit some categories more than others.

Moreover, designers' mentality depends on their background and testing different skill sets might induce some to focus more on certain aspects while considering others as insignificant. For example, engineers are probably more interested in technical and numerical aspects, at the expense of aesthetic or user experience.

Second, different example features could have been used, such as the gas press or the crushing plate. The experiment focused on their number, but did not examine *which* example ideas led to the most fixation. It's likely that some were used more than others, indicating a broader difficulty in finding alternatives and then limiting creativity.

Third, only two types of representations were investigated. Further studies should deepen the effect of others, such as CAD, photographs, physical models, or text. Research has already shown [1] that sketch examples inspire higher novelty and quality ideas than text descriptions. Other visual representations, being less immediate to produce and often more detailed, might promote fixation more than sketches.

Moreover, when conveying information, style and ability to sketch are sometimes as important as the design itself. Drawing has its own language and the designer's *forma mentis* affects which details are highlighted and which ones are left to intuition.

Finally, the influence of combining different types of representations on creativity should also be studied. Specifically, it should be investigated whether combining function trees with other methods affects fixation in the same manner they do with sketches, with different advantages and disadvantages, or if there are different outcomes.

VI. Conclusions

In conclusion, sketches often lead to fixation, while function trees enhance both quantity and quality of creative ideas. Combining these representations fixates more on example features due to added constraints but facilitates idea generation through easier abstraction.

This happens because some representations induce fewer cognitive biases, allowing for greater exploration of the *c-space*, though prior designs often serve as starting points to find alternatives. Personal experience supports the effectiveness of integrating visual and functional models.

Further research should investigate how designers' different skill sets influence fixation, which specific elements they tend to fixate on, and how other types of representations, and their combination, impact design creativity.

References

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