

DIFFERENCES IN ANALOGICAL SOURCE SELECTIONS BETWEEN DESIGNERS AND NON-DESIGNERS DURING THE COLLABORATIVE ANALOGICAL DESIGN PROCESS

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ABSTRACT

The selection of an analogical source is a critical step in the design-by-analogy process. Previous researchers have explored the reasons and preferences of individual designers or design teams in selecting analogical sources. Non-designers, who instead have more knowledge of other fields, may offer new possibilities for retrieving novel analogical sources. This study focuses on differences in the selection of analogical sources between collaborative design teams composed of designers and non-designers. There are indeed significant differences in the selection of the source type, the reasons for selecting the source, the level of abstraction in inspiration stimuli, and the novelty of design ideas between designers and non-designers. This work may provide theoretical guidance for the development of collaborative design tools and methods for teams composed of designers and non-designers with different knowledge bases.

Keywords: Creativity, Industrial design, Analogical source, Collaborative design, Collaborative analogical design

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Cite this article: Lu, H., Sun, G., Xu, J., Su, P., Tang, X., Zhang, Y. (2023) 'Differences in Analogical Source Selections between Designers and Non-Designers during the Collaborative Analogical Design Process', in *Proceedings of the International Conference on Engineering Design (ICED23)*, Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.149

1 INTRODUCTION

Analogy is a problem-solving strategy which works based on the transfer and mapping of knowledge from a ‘source domain’ to the ‘target domain’ (Gentner, 1983; Ball et al., 2004; Appleton and Short, 2008). Analogical thinking reflects the ability to frame problems; specific procedural steps help designers to solve ill-defined problems (Casakin, 2004). However, the process of matching familiar source case characteristics to design goals tends to create fixations that threaten creativity (Jansson and Smith, 1991; Chan et al., 2015). Bringing non-designers into the analogical design team is an effective means of identifying cross-domain analogical sources and finding novel design solutions. Despite a lack of specialised design knowledge, skills, or experience, non-designers have a significant advantage in defining design problems and proposing innovative solutions (Self, 2017; Atkinson, 2017). In this study, we investigate analogical collaborative design processes involving multidisciplinary teams composed of designers and non-designers.

The biggest difference between a designer and a non-designer is the availability of professional design knowledge and skills (Bassi 2017). Here, we define ‘designers’ as postgraduate students with more than seven years of product design education or professional designers with at least three years of product design experience. Non-designers are, naturally, a much larger group of people; we define ‘non-designers’ in this study as postgraduate students from non-design-related professional backgrounds. With reference to Qiu et al.’s (2021) disciplinary classification, postgraduate students from engineering, anthropology, psychology, computer science, fine arts, and sociology backgrounds (i.e. adjacent to the design discipline) were selected as representative non-designers (Dykes et al. 2009). Below, we discuss differences in the selection of source types, reasons for selecting certain sources, levels of abstraction in inspiration stimuli, and design idea novelty between designers and non-designers as observed in this study. The findings will provide guiding principles for design education and analogical design practice.

2 BACKGROUND

2.1 Analogical distance

Previous scholars have generally used analogical distances to characterise the distance between source and target domains (Keshwani and Chakrabarti 2017). Different analogical distances represent different degrees of similarity between the analogical source and the design target. Analogical sources can be divided into within-domain and between-domain categories according to their analogical distance (Alipour et al. 2017). The former falls into the domain near the design problem, while the latter is in a domain rather outside of the design-problem domain.

Many scholars also classify analogical distance as distant, middle, or near sources (Gonçalves et al. 2013; Cao et al., 2018). There are significant differences in the effects of different analogical sources on design results. Chan (2011) found that distant and less-common source cases can enhance the novelty and quality of design solutions. Fu (2013) found an appropriate analogical distance between ‘far’ and ‘near’ known as the ‘sweet spot’. Identifying the sweet spot enhances the creativity of design solutions. In this study, we divided analogical sources into near, middle, and distant domain sources at three different distances (Table 1).

In this study, we explore the differences in the selection of analogical sources by designers and non-designers. Designers are accustomed to adopting ‘solution-focused’ design strategies. They often use previous design experience to generate an idea quickly rather than developing a wider range of alternative conceptual solutions. Non-designers (novices), on the other hand, often adopt a ‘problem-focused’ strategy and are less likely to be satisfied with a singular, early solution (Cross 2004). Their extensive disciplinary background also opens up new possibilities for retrieving analogical sources outside the design-problem domain.

H1: During collaborative analogical design, designers tend to use near-domain sources while non-designers tend to use distant-domain sources.

Table 1. Analogical sources

Type of analogical source	Explanation	Example (unmanned vehicle design problem)
Near-domain source	Domain of the analogical source is similar to the domain of the problem (target) to be solved.	Courier vehicles, intelligent logistics vehicles, modular vehicles, food delivery vehicles, etc.
Middle-domain source	Analogical source is in a transitional space between the near and distant domains; its domain is close but not identical to the domain of the problem to be solved (target).	Express cabinets, shared chargers, box lockers, holding boxes, conveyor belts, etc.
Distant-domain source	Domain of the analogical source is biological or otherwise entirely different from the domain of the problem to be solved (target).	Bats, ants, beehives, kangaroos, baguettes, etc.

2.2 Reasons for selecting an analogical source

The reasons behind analogical source selections are a hot topic in design research. [Ozkan and Dogan \(2013\)](#) categorised designers' reasons for selecting analogical sources into the categories of function, form, originality, symbolism, aesthetics, design process, nature, and structure. Their findings suggest that expert designers select analogical sources based on the design process, while novices select analogical sources primarily based on function. By analysing experimental data from an outdoor furniture analogical design process, [Chai \(2015\)](#) added three new reasons for source selection: Experience, physical property, and feeling. It is possible that expert designers prefer experience and aesthetics as analogical sources while novice designers are more likely to prioritise symbolism and function. [Alipour et al. \(2017\)](#) coded architects' reasons for selecting analogical sources into 11 categories including function, form, originality, symbolism, and aesthetics. They found that function, climate, and symbolism increase the novelty of design solutions while aesthetics or economy of time hinder novelty.

The reasons for selecting certain analogical sources are related to the level of design expertise of the participants. Both non-designers and novice designers lack the knowledge and experience of design specialists though their reasons for selecting analogical sources may be similar. We propose the following, based on the critical analysis of existing research regarding the reasons for analogical source selections.

H2: During the collaborative analogical design process, designers tend to select sources for form, aesthetics, feeling, and experience reasons while non-designers prefer to select sources for reasons of nature, originality, and function.

2.3 Inspiration stimuli of different levels of abstraction

Inspiration stimuli are the external elements upon which designers consciously draw as existing resources to consider design problems and generate ideas ([Eckert et al., 2000](#)). Inspiration stimuli create short-term memory cues in the brain which reveal knowledge and experience stored in the long-term memory to activate associated ideas ([Perttula and Sipilä, 2007](#)). Textual descriptions and visual stimuli are the most common inspiration sources used by designers ([Cai et al., 2010](#); [Casakin, 2010](#)). [Linsey et al. \(2007\)](#) used WordTree to generate structured textual descriptions with different levels of abstraction as a foundation for designers to find potential analogical sources. The level of abstraction of the textual description corresponds to the level of the WordTree structure. A higher position on the tree indicates more abstract vocabulary. Other researchers classified the level of concept (i.e. design) abstraction into seven different levels: Part, organ, input, phenomenon, effect, state, and action ([Srinivasan and Chakrabarti 2010](#); [Keshwani et al. 2017](#)).

Within the specific context of analogical design, we define the abstraction of analogical stimuli according to five levels: Very abstract (action), abstract (state), middle (phenomenon and effect), concrete (organ and input), and very concrete (part) (Table 2). Consider the designer's advantages in dealing with form, material, structure, function, and other elements of product design which are closely related to organs, inputs, and components. Some of the non-designers who participated in this study have backgrounds in engineering, psychology, and computer knowledge. They tend to be more

sensitive to abstract stimuli such as principles, mechanisms, and phenomena. We developed our third hypothesis.

H3: During the collaborative analogical design process, designers prefer to use concrete inspiration stimuli while non-designers prefer to use abstract inspiration stimuli.

Table 2. Inspiration stimuli with different levels of abstraction

Analogical stimulus abstraction level		Explanation	Example (unmanned vehicle design problem)
Very concrete	Parts	Components and materials that constitute the product	Cargo storage devices
Concrete	Organs	Properties and conditions of the product	Adding obstacle avoidance
Middle	Input	Interaction of products with external material, information, and energy	Each goods unit can be taken out automatically
Abstract	Phenomenon and Effect	Principle or mechanism behind a product's function	The principle of preventing collisions with vehicles and walls
Very abstract	State and action	Changes in product attributes triggered by interaction between the product and its environment	Hazardous distance warning status

2.4 Evaluating design idea novelty

Quantity, quality, novelty, and diversity are valid evaluation indicators of ideas based on the principles of statistical experimental design (Shah et al., 2003). Novelty, as an indicator of the degree of innovation in a conceptual solution, is often used to evaluate analogical design ideas (Casakin, 2010; Fu et al., 2013). Novelty measures the degree to which an idea is unexpected or unusual compared to other ideas (Shah et al., 2003).

Many scholars have attempted to quantify the novelty of design ideas. For example, van der Lugt (2000) suggests that the 'tangential' structure of a linkography represents a novel design idea. Cai et al. (2010) found that the number of design alternatives that are distinct from a previous solution effectively characterises the novelty of a design idea. Expert scoring is also an effective means of evaluating the novelty of analogical design ideas (Goldschmidt and Smolkov, 2006; Alipour et al., 2017).

One of the aims of the present study is to compare the novelty of design ideas proposed by designers and non-designers in a collaborative analogical design process. Designers tend to propose relatively limited alternatives rather than develop completely novel solutions during the design process (Cross, 2004). By contrast, the unique domain knowledge of non-designers offers new possibilities for finding cross-domain analogies and generating novel design ideas (Yu et al., 2016). We developed our fourth hypothesis accordingly.

H4: Design ideas proposed by non-designers are more novel than those proposed by designers during the collaborative analogical design process.

3 METHOD

We explored differences in the selection of the type of analogical source, the reason for selecting the source, the level of abstraction of the inspiration stimuli, and the design idea novelty between designers and non-designers. Participants were asked to experiment in their everyday working environment to minimise interference from external environmental factors. After the experimenter had introduced the subjects to the design task and the design process, each group of subjects participated in the experiment via the collaborative design software MasterGo. Subjects were notified of the necessary time to complete tasks without other interference throughout the design process.

3.1 Design task

In recent years, the COVID-19 pandemic has ravaged the world and isolation of infected individuals has become the norm. The task given to participants was to design an unmanned vehicle to deliver supplies to quarantined people during COVID-19 lockdowns. The unmanned vehicle can transport 200 kg of household goods or medicine at a time.

3.2 Participants

We recruited 16 designers (8 male, 8 female) and 16 non-designers (7 female, 9 male) to participate in this study. The designers are postgraduate students with seven years of product design education and professional designers with over three years of product design experience. Non-designers are postgraduate students from non-design disciplines (e.g. electrical engineering, mechanical engineering, geology, computer science, psychology) as shown in Table 3. We randomly selected two non-designers and two designers to create each collaborative design team. Every team completed the design task independently.

Table 3 Non-designers' disciplinary affiliations and areas of expertise

Disciplinary affiliation	Area of expertise	Number of participants
Engineering	Electrical Engineering	2
	Geological Engineering	1
	Marine Engineering	1
	Mechanical Engineering	1
Computer Science	Computer Science and Technology	2
	Software Engineering	1
Fine Arts	Fine Art	1
Sociology	Sociology	1
	Anthropology	2
Psychology	Applied Psychology	2
	Psychology	2

3.3 Procedure

We developed a collaborative analogical design process based on the Wordtree method (Linsey et al. 2012) as shown in Figure 1. Before the experiment, we created an online WordTree generation environment on the MasterGo platform. In the first stage, the groups began with an online brainstorming session to discuss the design problem and re-represent it using three key descriptors (Linsey, 2007). The key problem descriptors included the mission description, user requirements, and key functions. Each member created an online WordTree in the second stage using rotational brainwriting based on the descriptors identified in the first stage. Once complete, they then took turns adding to and supplementing the WordTree created by the other three members of their group. In the third stage, the experimenter aggregated all WordTrees into a complete inspiration stimuli map. Participants selected specific textual descriptions from this map to find potential analogical sources. Google Image was then used to search for each associated source. Participants used the search results in the fourth stage to generate final design ideas, which were submitted in the form of sketches. Participants were asked to output as many designs as possible within the time limit. In the fifth stage, the experimenter surveyed the subjects retrospectively using an open-ended questionnaire.



Figure 1. Experimental procedure

3.4 Coding scheme

We used a coding scheme adapted from Chai et al. (2015) to analyse the experimental data and extract the reasons for analogical source selections. Table 4 lists the categories, explanations, and examples of the reasons we identified.

Table 4. Coding scheme

Category	Explanation	Example
Function	Beneficial role played or effectiveness achieved	Radar may be a good analogical source as it can detect the surroundings in real-time and assist in the safe driving of unmanned vehicles.
Form	Sources are similar in shape and visual appearance to design target	If the shape of the unmanned vehicle attracts attention, the incidence of safety accidents could be minimised. Designing unmanned vehicles in the shape of a long loaf of bread may achieve this goal.
Originality	Design ideas that are distinctly different from the norm	A 'mother' vehicle and 'daughter' vehicle structure (based on the kangaroo) could efficiently transport and distribute supplies.
Symbolism	Association from concrete object to abstract meaning	Health QR codes often used by people travelling during COVID-19 are a potential source as they express health-and-safety-related imagery.
Nature	Using nature (animals or plants) as sources	Ants perform wayfinding by identifying gas molecules. Unmanned vehicles could use a similar working principle to deliver supplies.
Structure	Organisational relationship among essential elements of the analogical source	A honeycomb hexagonal structure may be effective in driverless vehicles.
Aesthetics	Forms, images, and scenes that are visually pleasing	The stimulus 'ultraviolet radiation' evokes fireflies on a summer night.
Experience	Participants have worked on similar design projects	The design task is reminiscent of a food delivery robot design project, thought the delivery robot is much smaller and better-suited to navigating office buildings.
Feeling	Sensory or emotional experience of the participant	The warning signals used by animals could be replicated for unmanned vehicles. Common examples are cats arching their backs when danger is perceived or birds swelling their bodies and erecting their feathers to protect their eggs.

3.5 Metrics

We used an expert scoring method to assess the novelty of design ideas. With reference to [Alipour et al. \(2017\)](#), we ranked novelty corresponding to five levels: Very common, common, middle, novel, and very novel (denoted '1' to '5', respectively). Rank 1 represents very common and ordinary design ideas while Rank 5 implies very rare, unusual, or uncommon design ideas. We invited two industrial design experts with over eight years of experience to evaluate our participants' design ideas. We used Kappa calculations, which correspond to different degrees of agreement, to test their results. A consistency score of 0.61-0.80 indicates general agreement between the experts' reviews ([Landis and Koch, 1977](#)). The two experts first evaluated the design solutions of four participants independently and then discussed the differences in their evaluation results. This procedure was repeated until the consistency score of the evaluation exceeded 0.75, which ensured both the independence and consistency of the result.

4 RESULTS

Table 5 lists the different participants' selections of analogical source types. We conducted a chi-square test ($\chi^2(2) = 42.039, p < 0.001$) to find a significant difference in the source types selected by designers and non-designers. Post-hoc tests comparing the standard residual values with the critical values of -1.96 and 1.96 show that designers tended to select middle-domain sources (std. residual = 2.6) and non-designers tended to choose distant-domain sources (std. residual = 3.9).

Table 5. Frequencies, standard residuals of analogical source types selected by different participants

	Near domain	Middle domain	Distant domain
Non-designers	24(-0.3)	34(-2.9)	58(3.9)
Designers	33(0.2)	91(2.6)	21(-3.5)

To test Hypothesis 2, we conducted another chi-square test ($\chi^2(8) = 78.463, p < 0.001$) which showed a significant difference in the reasons for source selection between designers and non-designers. Table 6 shows the relationship between the different participants and their reasons for selecting a source. Post-hoc tests show that the main reasons designers selected certain sources were form (std. residual = 2.4) and aesthetics (std. residual = 3.1). The main reasons that non-designers selected certain sources were structure (std. residual = 2.3), nature (std. residual = 2.7), and originality (std. residual = 2.8).

Table 6. Frequencies, standard residuals for reasons behind selection of analogical sources by different participants

	Function	Form	Originality	Symbolism	Nature	Structure	Aesthetics	Experience	Feeling
Non-designers	30 (-0.9)	16 (-2.7)	41 (2.8)	7 (-0.7)	57 (2.7)	49 (2.3)	7 (-3.4)	6 (-0.1)	8 (-1.6)
Designers	48 (0.8)	52 (2.4)	18 (-2.5)	13 (0.6)	31 (-2.5)	29 (-2.1)	45 (3.1)	8 (0.1)	23 (1.5)

Table 7 shows the relationship between different participants and the levels of abstraction of their selected inspiration stimuli. We conducted a chi-square test ($\chi^2(4) = 17.8, p = 0.001$) which indicates a significant difference in inspiration stimuli abstraction levels between designers and non-designers. Post-hoc tests indicate that designers tended to select concrete inspiration stimuli (std. residual = 2.2) while non-designers tended to select abstract inspiration stimuli (std. residual = 2).

Table 7. Frequencies, standard residuals of inspiration stimuli selected by different participants

	Very abstract	Abstract	Medium	Concrete	Very concrete
Non-designers	9 (0.5)	35 (2)	21 (0.1)	13 (-2.3)	8 (-0.2)
Designers	7 (-0.5)	18 (-1.9)	22 (-0.1)	38 (2.2)	10 (0.2)

We conducted a chi-square test ($\chi^2(4) = 20.284, p < 0.001$) to test Hypothesis 4 which shows a significant difference in the novelty of the design ideas proposed by designers versus non-designers (Table 8). Post-hoc tests show that designers' ideas were more common (std. residual = 2.1) while non-designers' ideas were more novel (std. residual = 2.3).

Table 8. Frequencies, standard residuals of design-idea novelty by different participants

	Very common	Common	Middle	Novel	Very novel
Non-designers	5 (-0.5)	6 (-2.3)	10 (-0.1)	23 (2.3)	8 (0.7)
Designers	9 (0.5)	27 (2.1)	13 (0.1)	9 (-2.1)	6 (-0.6)

5 DISCUSSION

In this study, we investigated the differences between participants in a collaborative analogical design process across four areas: Selected analogical source types, levels of abstraction in inspiration stimuli, reasons for selecting analogical sources, and the novelty of design ideas. The results show that designers tend to select middle-domain sources and non-designers tend to select distant-domain sources, partially supporting Hypothesis 1. We speculate that designers' preferences for middle-domain sources are the result of a trade-off between the novelty and quality of design concepts (Srinivasan 2018). This effectually partial consideration of design targets helps to generate solutions that are rich in detail (Cao et al. 2018). Distant or uncommon sources often lead to more novel design ideas (Chan et al., 2015). Non-designers may prefer distant sources because they seek distinctive design solutions based on their unique knowledge of their own domain. A typical example is a non-

designer with a background in oceanography and geology, who selected sonar as the source to solve an obstacle avoidance problem for the delivery vehicle.

Hypothesis 2 is also partially confirmed. Designers selected sources primarily for form and aesthetics while non-designers selected sources primarily for structure, nature, and originality. The reasons behind 'aesthetic' and 'form' selections reflect designers' sensitivity to the visual materials often used in the design and their generally more prominent aesthetic awareness. We were surprised to find that designers selected 'feeling' as a reason unlike other participants. This suggests that designers seek to enhance the sensory and emotional experience of a product by evoking the user's emotions and giving them new meaning (Verganti, 2008). By contrast, the selection of 'originality' reasons reflects an initial desire in non-designers to pursue distinctive design solutions. This is consistent with Chai et al.'s (2015) finding that originality explains design novices' choices of analogical sources. Unlike design novices, non-designers with knowledge of other domains are more likely to succeed in finding distant sources. Furthermore, sources of inspiration from nature inspire more creative designs (Ozkan and Dogan, 2013), which is consistent with the reasons why non-designers considered 'nature'.

Our results fully confirm Hypothesis 3; designers preferred concrete analogical stimuli and non-designers preferred abstract analogical stimuli. Designers gravitated toward concrete analogical stimuli such as the use of film materials, the addition of obstacle avoidance, the addition of insulation, and the use of modular design. Concrete analogical stimuli help designers draw on previous experience to achieve design goals with a 'path-of-least resistance' strategy. Non-designers, conversely, gravitate toward abstract (phenomenon and effect) inspiration stimuli. We speculate that this is related to the engineering and computing backgrounds of some of our participants, which suggest that they are good at abstracting the principles and mechanisms behind more concrete phenomena. We also found that the preferences among our participants for 'very concrete' stimuli are limited. We speculate that this is related to the redefinition of the design problem by participants through their discussion during the experiment. Kokotovich and Dorst (2016) found that modest combinatorial divergence from existing concepts increases designers' levels of abstraction, making the selection of very specific 'parts' as inspiration stimuli very rare. Our participants did not tend to select 'state' or 'action' as analogical stimuli resulting in a limited quantity of 'very abstract' stimuli. High levels of abstraction require that participants can shift paradigms and advance prior art via discontinuity. Only visionary, masterful designers frequently demonstrate high levels of abstraction in their design processes.

The design ideas proposed by non-designers in this study are significantly more novel than those proposed by designers. To this effect, Hypothesis 4 is fully confirmed. We speculate that the design goal of 'time economy' (Alipour et al. 2017) leads designers to improve on existing design solutions rather than developing novel alternatives wherever possible. The matching of similarities between design cases and goals may also lead designers into states of fixation (Moreno, 2016). For example, the inspiration of 'module design' allowed one designer to quickly associate shared rechargeables, courier cabinets, power exchange stations, and vending machines as sources and eventually produce similar design solutions. Non-designers do not have the experience that would lead them toward the 'path-of-least resistance' in this context. Thus, novelty became one of their main goals during the collaborative analogy design process.

6 CONCLUSION

The incorporation of non-designer members on an analogical design team is a workable means of accelerating innovation. We investigated differences in the selection of analogical sources between designers and non-designers during collaborative analogical design processes in this study. Our conclusions can be summarised as follows. (1) Designers tend to select middle-domain sources and non-designers tend to select distant-domain sources. (2) Designers select sources mainly for form and aesthetics related reasons while the main reasons that non-designers select certain sources are structure, nature, and originality. (3) Designers prefer concrete inspiration stimuli while non-designers prefer abstract inspiration stimuli. (4) The design ideas proposed by designers are more novel than those of non-designers. Our findings may provide theoretical support for guiding collaboration among design-team members from multidisciplinary backgrounds, the deployment of multiple levels of expertise, and the development of next-generation of collaborative tools for analogical innovation.

This work is not without limitations. First, the expert scoring method is somewhat subjective. The precise evaluation of design ideas is difficult to achieve. In addition, the broad definition of ‘non-designers’ covers a wide range of people. Indeed, non-designers from different professional backgrounds may select different sources of analogy. For our purposes, we selected only postgraduate students with backgrounds in engineering, computer science, art, sociology, and psychology disciplines. Future research could expand the non-designer sample.

This work is a preliminary exploration of collaborative analogical design with multidisciplinary teams; the teams in our context consist of non-designers with diverse knowledge bases and designers with extensive design experience. In the future, we will consider the impact of factors such as disciplinary background, knowledge level, and expertise among multidisciplinary team members on their analogical design outcomes.

ACKNOWLEDGMENTS

This work was supported by the National Key Research and Development Program of China under Grant number 2021YFF0900600; National Natural Science Foundation of China under Grant number 51675382; Open Research Subject of Research Center of Industrial Design under Grant number GYSJ17-019; New Liberal Arts Research and Reform Practice Project of the Ministry of Education of China under Grant number 2021020014; Fundamental Research Funds for the Central Universities under Grant number 22120210243; Post-Funded Project of Ministry of Education Philosophy and Social Sciences Research under Grant number 18JHQ095; and Style of Study Building Grant Scheme Support Project under Grant number XFCC2021ZZ001-B89.

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