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# Do Creativity Metrics from Design Research Correlate with Those from Psychology?

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## ABSTRACT

In this paper, we explore measurements of design creativity through metrics related to the processes used in designing and relate them to the metrics used in psychology for idea creativity, ie, novelty and fluency. Our goal was to test the reliability of psychometric measures of creativity to assess creativity in team design. We studied 19 teams of 3 professional engineers that engaged in a one hour-long design task. Design tasks have a greater ecological validity than single repetitive tasks like the AUT and the RAT. Engaging in a design task involves a wide range of cognitive activities, which contribute to creative ideation and to expanding the design space. This study focused on the relationship between the teams' design idea creativity and design behaviors during the task. We explored to what extent design collaboration between teammates, design evaluation and the co-evolution of the problem-solution space relate to the psychometric measures of idea creativity. Results suggest no specific trend in the correlation between collaboration and idea creativity as measured by the metrics used in psychology, while more cognitive focus on problem-solution co-evolution negatively correlates with these measures of idea creativity. The paper concludes with potential explanations for this lack of correlation.

## Introduction

As design problems are wicked (Rittel & Webber, 1973) and ill-structured (Simon, 1973), designers engage in the design process by constructing and structuring their design space. The design space is the space of ideas that are introduced into the design as the designer is designing (Gero & Milovanovic, 2022). All concepts that emerge while designing structure the design space, which is situated in relation to the design context and the designer's expertise (Schön, 1983). In design fields, creative thinking is valued as it can lead to innovations (Brown, 2008). Creative ideas require novelty (Boden, 1990) and usefulness (Runco & Jaeger, 2012). Boden (1990) also introduced a third metric for creative ideas, surprise, but this has not been taken up in the cognitive psychology literature, which has focused only on the metrics of novelty and usefulness. Surprise or unexpectedness has been explored in the design literature (Brown, 2012; Gero, 1996; Maher, Brady, & Fisher, 2013; Suwa, Gero, & Purcell, 2000) but will not be considered further here. In designing as in other creative activities, creative ideation can be two complementary processes designers engage in: generating ideas which is associated with divergent thinking and evaluating ideas that is associated with convergent thinking

(Cropley, 2006; Goldschmidt, 2016; Guilford, 1967). Generating design ideas supports developing original or novel ideas, by expanding the design space. On the other hand, evaluating ideas serves to assess how useful and novel one idea is to address the design requirements. In the past decades, creativity and design research explored diverse topics such as the underlying cognitive processes of a creative thinker, personality traits and behaviors of creative thinkers, the environment and context effects on creative work, amongst others, that also became the focus of design teams creativity research (Finke et al., 1992; Guilford, 1966; Kurtzberg & Amabile, 2001).

The methods employed to assess creativity in cognitive psychology rely mostly on divergent thinking tests like the Alternate Uses Task (AUT) (Guilford, 1966, 1967), the Remote Associate Test (RAT) (Mednick, 1962) or problem-solving tasks (Long, 2014). In design research, creativity is studied within a design situation when an artifact is designed (Crilly & Moroşanu Firth, 2019). Creative thinking tests are limited when studying design creativity, as they fail to capture the situatedness of designing and do not address the range of processes that designing involves.

In this paper, we explore some measurements of design processes through metrics stemming from the analysis of design protocols and determine how they correlate with the cognitive psychology measurements of creativity, namely, tests for divergence. The study examines to what extent design behaviors correlate with generating creative ideas in situ, within a design task setting. Design tasks have a greater ecological validity than single repetitive tasks like the AUT and the RAT. They involve a wide range of cognitive activities, which contribute to creative ideation processes engaged when developing concepts. Designing occurs across months or even years. Here, we aim at identifying design processes that could be proxies of idea creativity, where idea creativity is determined using single measures from psychology.

We will explore correlations between idea creativity measured using a cognitive psychology SemDis, an automated creativity assessment based on concepts' semantic distance (Beatty & Johnson, 2020), and designers' processes that generate and evaluate ideas. This study draws on the analysis of 19 teams of three professional engineers that participated in hour-long design sessions.

## Background

### *Creativity of ideas in design*

Creative ideas need to be novel, original and useful within the design context (Sarkar & Chakrabarti, 2014) to be innovative (Oman et al., 2013). Boden (1990) defines creativity as at least an ability to generate novel and valuable ideas. Those two dimensions encompass two complementary facets of a creative idea: novel meaning the idea is new to the person who generated it (P-creative ideas in Boden's terms) or to the world (H-creative ideas) and valuable implying the idea is useful and interesting.

In design thinking, novelty refers to the uniqueness of one idea and is relative to other ideas addressing the same problem within that design situation context. Dorst and Cross (2001) discuss the novelty of ideas in design through an example of a design task for a litter disposal system in trains. All the teams of designers had the same idea, to separate newspaper litter and other type of litter. Yet, each team considered this idea to be novel, original, unique. From an external stand point, the solution of separating newspaper litter and other type of litter is not novel as all the teams had the same idea, but is a form of situated novelty within each team's design context (Suwa, Gero, & Purcell, 2000).

Creativity in design, as a process describes designers' capacity to frame a problem in an unexpected way to generate novel ideas to a design problem (Oman, Tumer, Wood, & Seepersad, 2013), to create novel combination of ideas and transform current ones into creative ones (Boden, 1998).

### *Design processes to support creative ideation in teams*

Cognitive behaviors, team dynamics and personality traits all tend to have an impact on creative ideation (Guilford, 1966; Kurtzberg & Amabile, 2001; Toh & Miller, 2016). Creative thinking in design relies on complementary processes: generating new ideas, evaluating ideas (Runco & Jaeger, 2012), and recombining ideas (Boden, 1998). In design teams, interactions between designers also influence creative ideation (Dorta, Lesage, Pérez, & Bastien, 2011). In the following sections, we will discuss four design behaviors that relate to creative design ideation: idea fluency, evaluating ideas, design collaboration and co-evolution of the problem and solution spaces of ideas. These are commonly used metrics in design to predict the creativity of design outcomes.

### *Generating design ideas to increase creative potential*

Shah, Smith, and Vargas-Hernandez (2003) describe two metrics of design creativity by measuring quantity and novelty of ideas. The assumption is that a richer set of ideas explored can lead to a more creative concept. To advance in the design process, designers generate numerous concepts that are sometimes included in the final design, and sometimes discarded along the way (Starkey et al., 2016). Generating numerous ideas helps explore different directions and can lead to selecting novel ideas. Divergent thinking processes serve to structure the design problem through the generation of multiple ideas and preliminary designs (Goel, 1995). Idea fluency, or the quantity of idea within a set period of time, influences the effectiveness of idea generation, one process of creative ideation. A high idea fluency is considered a positive characteristic as research has demonstrated that more ideas tend to correlate with higher creativity (Clark & Mirels, 1970). Generating multiple ideas provides a range of possibilities from which to develop a concept addressing a design problem by increasing the size of the design space and providing opportunities to combine current ideas (Boden, 1998).

### *Evaluating ideas usefulness and originality*

Evaluating initial concepts serves to analyze and structure the design space, as cognitive way-finding

(Goel, 1995). It is also a means to select the most relevant or useful ideas that would fit within the design requirements and situation, and to assess its originality. Designers need to converge and develop one solution for their design requirements, relying on their design knowledge to make these decisions (Cropley, 2006). Designers' knowledge of their field and expertise supports their ability to combine ideas or make unexpected connection between unrelated solutions or partial solutions (Cropley, 2006), that can result in creative ideas. In this process, designers synthesize information gained from the design problem space, by evaluating early solutions and detailing a proposal.

### ***Team collaboration and team creativity***

Team performance in a design team is affected by team composition, organizational culture, conflict or shared cognition within a team (Salas, Shuffler, Thayer, Bedwell, & Lazzara, 2015). For example, in their empirical study, Menold and Jablowski (2019) demonstrated how cognitive style diversity positively impacts the design output. Social relationships also affect the team process as design collaboration is socially situated (Bucciarelli, 1988). In their study on micro-conflicts, Paletz, Chan, and Schunn (2017) found that successful teams manage to reduce uncertainty in the design process after having social micro-conflicts, whereas unsuccessful design teams experience an increase in design uncertainty after experiencing social micro-conflicts.

The social dimensions of team collaboration impact the team design process and their creative thinking process. Guilford (1966) introduced the notions of creative potential or what one brings as a possible creative performance based on personality. This highlights two important elements that can affect a team's creativity: each designer's personality and trait, and how team members collaborate to produce a design. Areas of research in team level creativity range from research on how other's ideas change or influence one's ideas in a group, the evolution of ideas as ideas are reshaped to one's mind, team cultures (norms, values, ideas, environment) that affect the formulation of ideas (Kurtzberg & Amabile, 2001).

In their empirical study of team creativity, D'souza and Dastmalchi (2016) posit two types of team creativity: little creativity leaps and big creativity leaps. Little creativity leaps occur when a team member proposes a novel or original idea, while big creativity leaps relate to a collective convergence toward a solution. Team collaboration plays an

important role in big creativity leaps when the team negotiates and agrees on ideas to pursue in their design process. It is not clear yet to what extent increasing collaboration leads to more team creativity.

### ***Generating and evaluating ideas through the co-evolution of the problem-solution space***

Cross (2002) explored creative process strategies of exceptional designers. These designers follow similar strategies to engage in creative design: they take a systems approach to the problem, they frame the problem in a specific and personal way and they design following a first principle, to generate a solution shaped from experience. In other words, to succeed, designers create a match between the problem and solutions. The bridge created between problem and solutions has been observed in other empirical studies (Dorst, 2019; Dorst & Cross, 2001; Yu, Gu, Ostwald, & Gero, 2015). Seminal work on problem-solution co-evolution has set a conceptual model of that process at the core of design thinking (Maher & Poon, 1996).

By engaging in problem-solution space co-evolution, designers seek for a good fit between the design problem and solutions they generate by evaluating the match between both. As design problems become more complex, there is an increasing need for iterations and feedback loops between the problem and the solution spaces (Dorst, 2019).

Past research suggest that increased co-evolution of the problem-solution spaces favors creative ideation. Designers advance in the design process by formulating bridges between design elements in problem and solution spaces (Dorst & Cross, 2001). The co-evolution of the design space implies that processes happening in one or the other space influence the other and how the design activity unfolds (Maher & Poon, 1996). An "aha!" moment illustrates a mapping between an element in the problem space and the solution space, and is perceived as a creative step in a design process (Akin & Akin, 1996).

In their analysis of professional designers, Crilly and Moroşanu Firth (2019) observed co-evolution between several spaces and across multiple levels. Designers simultaneously explored a good match between multiple parts of the design solution and multiple parts of the design problem. In design teams, Wiltschnig, Christensen, and Ball (2013) also observed collaborative and individual co-evolution episodes. Previous empirical research on design teams pointed out that more effort on problem understanding (problem space) tends to positively correlate with the usefulness of ideas, but no clear trend has

appeared regarding the relationship between the time teams spend on problem understanding and problem solving (generating solution) and the creativity of design solutions (Chulvi, Sonseca, Mulet, & Chakrabarti, 2012).

## Research goal and hypotheses

The focus of the paper is to explore to what extent design behaviors in teams correlate with the creativity measures used in psychology – psychometric creativity measures. Based on previous research, our hypotheses are as follows:

- H1: Idea creativity (psychometric) positively correlates with fluency while designing.
- H2: Idea creativity (psychometric) positively correlates with evaluation while designing.
- H3: Idea creativity (psychometric) positively correlates with co-design while designing.
- H4: Idea creativity (psychometric) positively correlates with co-evolutions of the design problem-solution space while designing.

## Methodology

### Description of the experiment

This study is based on empirical results from a think-aloud protocol experiment that involved 57 engineering professionals from two companies (age mean = 48.2, SD = 8.7). The first company specializes in developing solutions for automotive safety whereas the second is a leader in providing systems and products for the aerospace and defense industry. In total, 19 teams of three engineers were formed randomly. All engineers were used to working in multidisciplinary teams as both companies follow lean or agile manufacturing and production processes in their product development. The engineers' backgrounds ranged from mechanical engineering, quality engineering, electrical engineering to manufacturing, computer science, and physics. All engineers had at least 10,000 hours of professional design experience. Of the 57 participants, 5 were women, 52 were men.

Each team was given the same task, to design a next-generation personal assistant and entertainment systems for the year 2025. They were invited to focus on what this system would be, how this system works and interacts with people, and what the personal assistant and entertainment system would provide to end users. The teams were each given 1 hour to develop a concept description and to sketch it on a white board. All team members were colocated and a research assistant stayed in the room as

participants developed their design. Toward the end of the design session, the research assistant asked the design team to verbally summarize their ideas for their final concept. Two teams failed to provide a clear final concept and were removed for the analysis.

The companies requested that the experiment be done outside of the work environment for privacy reasons. Each design session was video recorded to be later analyzed. Although the experiment was set in a controlled environment, the task and context provided a naturalistic type of creative task compared to repetitive tasks such as the AUT (Guilford, 1966) and the RAT (Mednick, 1962). This experiment provides an opportunity to study creativity embedded in a collaborative design situation.

In the following sections, the metrics used in this study are presented. It measures 1) the creativity of ideas and 2) teams' design behaviors and processes: generating ideas, evaluating ideas, collaborating and navigating the problem-solution space. All metrics stem from analyzing design protocols and could be applied to any design protocol. The goal is to assess what team design behavior correlate with the two measures of creativity used in the psychology literature.

### Measuring the creativity of design ideas

Novelty of design ideas is usually measured through subjective assessment of the final concepts carried out by experts. The Consensual Assessment Technique (CAT) to measure creative outcomes (Amabile, 1982) is widely used in design assessments to study creativity (Long, 2014). Although this method has proven to be a relevant approach to measuring the novelty of ideas, it requires resources to gather experts to evaluate designs. A recent web-based tool developed by Beaty and Johnson (2020), called SemDis, offers an alternative to CAT by measuring the semantic distance of the final concept to the design requirements. The SemDis tool to assess creativity is claimed as a robust alternative to CAT as it positively correlates to subjective creativity ratings, such as novelty ratings (Beaty & Johnson, 2020). This suggests that the higher the SemDis score, the higher the creativity of an idea. In this study, for each session, the final concept summarized by design teams was analyzed with SemDis (<http://semdis.wlu.psu.edu/>) to generate a creativity score. The input used as a requirement was "personal assistant and entertainment system." In other words, the score is the measure of the semantic distance between the design requirement ("personal assistant and entertainment system") and the verbal description of the final concepts formulated by the design teams.

## Measuring design behaviors

### Measuring design teams' generated ideas with idea fluency

Idea fluency or the quantity of ideas generated in a set period of time is important in creative ideation (Guilford, 1966). Fluency equates to the frequency of occurrence of new ideas over time. To measure idea fluency, we first identified ideas newly introduced into a design session by analyzing the transcribed design protocols of each team. The first occurrence of ideas can be considered as a form of situated novelty (Suwa et al., 2000). We will call ideas newly introduced into a design session by the shorthand "new ideas." We developed a Python script to automate this process using Natural Language Processing packages (NLTK, Natural Language Toolkit) to tokenize the transcribed protocols and extract nouns with NLTK Part of Speech tagging features. Nouns were selected because they capture design ideas such as "drone," or "phone." The second part of the script allows the identification of the first time each concept was formulated, capturing situated novelty. The fluency of ideas is determined as the slope of the cumulative occurrence graph of new ideas. A higher slope signifies a higher rate of occurrence of new ideas, hence a higher fluency.

### Measuring design teams' evaluation of ideas with FBS processes

Design idea evaluation is the process that allows the team to assess their usefulness and originality and is the basis on which a team moves forward with ideas. To measure the extent to which each design team evaluated their new ideas, we analyzed the distribution of design processes for the one-hour design sessions. To do so, we employed protocol analysis (Ericsson & Simon, 1984; Van Someren, Barnard, & Sandberg, 1994) and the Function Behavior Structure (FBS) ontology to identify design processes (Gero, 1990). Protocol analysis is a method from cognitive science used to determine cognitive processes based on verbal utterances. In design teams, the natural conversation between designers serves as the verbalization to be encoded. Codes are elements associated to cognitive concepts in designing (Gero & McNeill, 1998; Kan & Gero, 2017).

A general way to describe design knowledge is given by the FBS ontology (Gero, 1990). We chose the FBS ontology based on its widespread use in describing designing and its use in design protocol analysis (Bott & Mesner, 2019; Dantan, et al., 2019; Delle Monache & Rocchesso, 2016; Hamraz & Clarkson, 2015; Kan & Gero, 2017). The two papers that describe the foundations of the FBS ontology (Gero, 1990 and Gero &

Kannengiesser, 2014) have been widely used across design fields: architecture (Milovanovic & Gero, 2018; Yu & Gero, 2016), engineering (Hamraz & Clarkson, 2015; Masclet & Boujut, 2010), and software design (Hofmeister et al., 2007), amongst others.

We used this framework to encode design conversations as Functions, Behaviors or Structures. The FBS framework represents six design issues: Requirement (R) includes the design requirements specified by the client and comes from outside of the designer, Function (F) is what the design object is for: its teleology, Expected Behavior (Be) represents an behavior expected of the design object, Structure (S) represents elements and their relationships that go to make up the design object, Structure Behavior (Bs) is behavior derived from a structure, and Description (D) is an external representation of the design object (Gero, 1990; Gero & Kannengiesser, 2014).

The FBS ontology accounts for a total of eight cognitive design processes as a consequence of transitions between the six design issues, as shown in Figure 2: *Formulation*, a transition from a requirement (R) to a function (F), and/or from a function (F) to an expected behavior (Be), *Synthesis*, a transition from an expected Behavior (Be) to a design structure (S), *Analysis*, a transition from a design structure (S) to a behavior from structure (Bs), *Evaluation*, a transition from an expected behavior (Be) to a behavior from structure (Bs) and inversely, *Documentation*, a transition from a design structure (S) to a description (D), *Reformulation 1*, a transition from a design structure (S) to a different design structure (S), *Reformulation 2*, a transition from a design structure (S) to an expected behavior (Be) and *Reformulation 3*, a transition from a design structure (S) to a function F.

The protocols were transcribed, segmented and coded using the FBS ontology represented in Figure 1. A segment is that part of the verbalization that contains one and only one design issue and hence a single code. Each session was independently coded by two trained coders. Table 1 presents an example of a small part of a coded protocol. When a disagreement occurred, coders arbitrated each segment together, and relied on an external coder's input if they could not reach an agreement. In total, three coders worked in pairs to code the data (19 one-hour long protocols). The average Cohen's Kappa between coders was .73, which ensures the reliability of the data analyzed. The average coder agreement between coders and the final arbitrated session for all 19 sessions is 80%. Cohen's Kappa was not used as a measure between coders and the final arbitrated code since the final code is not dependent on any individual coder.

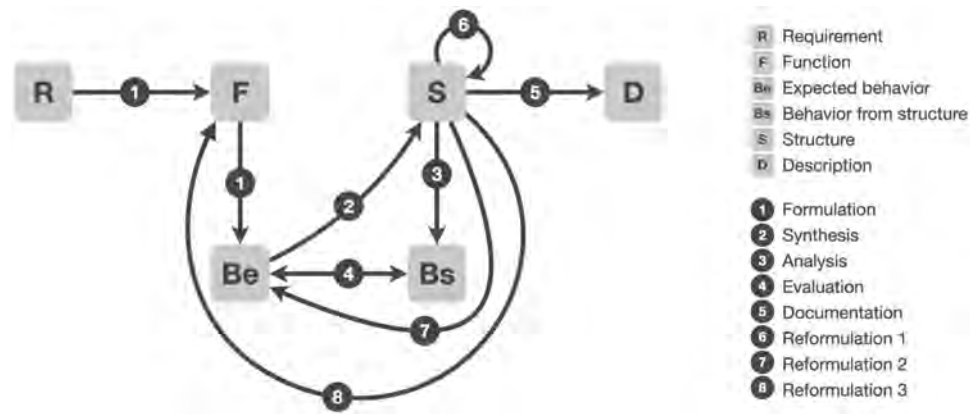


Figure 1. FBS ontology (Gero, 1990; Gero & Kannengiesser, 2014).

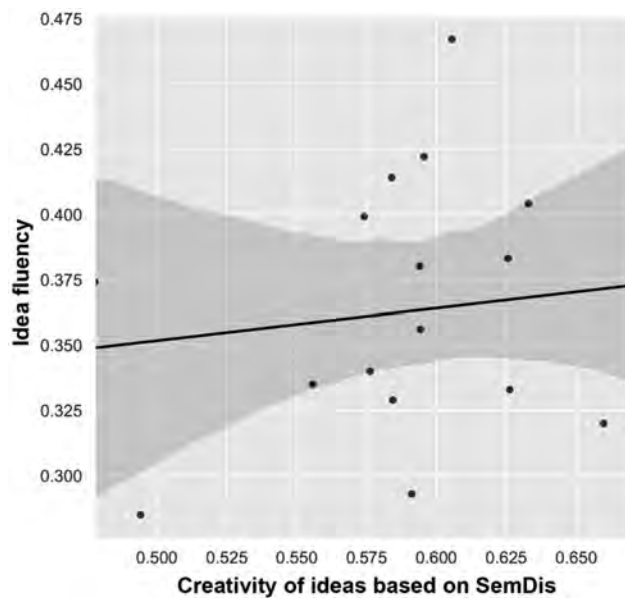


Figure 2. Design behavior *idea fluency* plotted against SemDis measurement.

Table 1. Example of part of a coded protocol with design issues identified through FBS codes and design processes derived from the transition from one design issue to the next.

| Utterance                                                    | FBS code | Design process  |
|--------------------------------------------------------------|----------|-----------------|
| It's got to be able to connect to all the in-home, you know. | Be       | -               |
| So, if you have a Wi-Fi. The Wi-Fi stuff ...                 | S        | Synthesis       |
| or Bluetooth                                                 | S        | Reformulation 1 |
| or whatever features                                         | S        | Reformulation 1 |
| and be able to network with all of them.                     | Be       | Reformulation 2 |
| And then you got to have, you know, with the TVs             | S        | Synthesis       |
| and then connecting                                          | Bs       | Analysis        |
| to your entertainment things.                                | S        | Synthesis       |

For each session, the distribution of each design process was measured. To evaluate ideas, a team carries out the analysis processes, that is an analysis of the behavior of a design structure (S), followed by the evaluation processes, that is a comparison between expected design behaviors (Be) and current design behaviors (Bs).

### Measuring design collaboration

Teams face other challenges than individual designers as they need to collaborate to move forward in their design process and develop creative ideas (Dorta et al., 2011; D'souza & Dastmalchi, 2016;). In this study, we analyzed collaborative interactions between each teammate to explore to what extent it impacted the team's measurement of design idea creativity. Every segment in the design protocols was coded with each designers' identifier.

FBS design processes are transitions from one specific design issue to another specific design issue (Figure 1). Therefore, a process formulated by a single designer, implies that both design issues forming a design process are verbalized by the same designer. We consider a co-design process as an FBS design process where one designer verbalizes the first design issue, and another designer verbalizes the following one. For example, designer A formulates the following expectation "what if you took the virtual reality and interacted it with something ... " and designer B responds with a design structure "Like smart TVs, you connect your system to a smart TV." In our framework, such interaction is defined as a collaborative synthesis ( $Be > S$ ) process between designers A and B. See Gero and Milovanovic (2019) for more details on the FBS co-design model.

### *Measuring design teams' co-evolution of the problem-solution space to track the interrelation of generating and evaluating ideas*

In a recent paper, Gero, Kannengiesser, and Crilly (2022) defined a co-evolution episode between the problem and the solution spaces in a design activity as a switch from a cognitive focus in the problem space followed by focusing on the solution space before going back to the problem space, or inversely. In this conceptualization of co-evolution, focus in one space influences the focus in the subsequent space.

As the co-evolution of the problem-solution spaces is often associated with creativity, we measured the number of co-evolution episodes design teams experienced during their design sessions. Based on the coded protocols, cognitive focus on either the problem or the solution space was identified. The following design issues, Requirement (R), Function (F) and expected Behavior (Be), are situated in the problem space while Structure (S), Behavior from structure (Bs) and Description (D) are part of the solution space. We developed a Python script to monitor co-evolution episodes, either from the problem space to the solution space back to the problem space or, from the solution space to the problem space back to the solution space. The distance threshold of five design issues was applied meaning that the episode happened within five segments in the coded design protocol (cf Table 1 for examples of segments). Five segments encapsulate the formulation of five distinct ideas and have been used previously as a suitable frame to measure co-evolution events (Gero et al., 2022).

## **Results**

The first section presents the results for each metric: the measurement of the final concept creativity and the teams' design behaviors and processes (generating ideas, evaluating ideas, collaborating and navigating the problem-solution space). The second section focuses on the correlations between the measurement of concept creativity and design behaviors.

### *Metrics of idea creativity and team behaviors*

#### *Measurement of the creativity of the final concepts based on SemDis*

The SemDis scores for each design session were calculated using the online SemDis tool (Beaty & Johnson, 2020). This SemDis tool computed the semantic distance between the final idea generated and the design requirements in 5 different models that relies on multiple corpuses (Table 2). The SemDis mean provides a unique composite score (SemDis mean) to assess the semantic distance for each design sessions on a scale of 0 to 2. A higher SemDis mean correlates with more creative ideas (Beaty & Johnson, 2020). In our dataset of 17 sessions, SemDis scored ranged from .49 to .67. The SemDis scores for this cohort had a mean of .59 (SD = .05). DT12 (SemDis = .67) had the most creative final concept compared to other teams based on SemDis and DT3 (SemDis = .48) produced the least creative final concepts.

#### *Design teams behaviors during creative ideation*

In a one-hour design session, teams verbalized a mean of 385 (SD = 70) unique ideas. Out of those unique ideas, a mean of 20.3% (SD = 6.75) ideas were unique to a design team, meaning that no other design team mentioned those ideas. Fluency (here fluency is measured against segments) can be determined by graphing the cumulative new idea occurrences against segments (Kan & Gero, 2017). The cumulative occurrence graph is linear for all design sessions with a mean slope of .36 (SD = .05).

The Evaluation processes, calculated with FBS protocol analysis, were a mean of 14.6% (SD = 5.1) of all the design processes.

The FBS collaborative design processes were a mean of 31.7% (SD = 5.1) of all the design processes.

The number of episodes of PS (Problem-Solution) co-evolution was normalized based on the total number of segments in each design session. The PS co-evolution episodes were a mean of 15.3% (SD = 3.7) of all the PS episodes.

Table 3 summarizes these results.

**Table 2.** SemDis results for each design team (DT) generated with the online SemDis tool (see Beaty & Johnson, 2020 for more information about SemDis).

| Design sessions | CBOW semantic distance 1* | CBOW semantic distance 2* | CBOW semantic distance 3* | TASA semantic distance | Glove Semantic distance | SemDis mean |
|-----------------|---------------------------|---------------------------|---------------------------|------------------------|-------------------------|-------------|
| Average         | 0.48                      | 0.58                      | 0.60                      | 0.90                   | 0.39                    | 0.59        |
| SD              | 0.03                      | 0.05                      | 0.05                      | 0.05                   | 0.04                    | 0.05        |

\*CBOW model 1 is built on a concatenation of the ukwac web crawling corpus (~ 2 billion words) and the subtitle corpus (~385 million words). CBOW model 2 is built on the ukwac web subtitle corpus only. CBOW model 3 is built on a concatenation of the British National Corpus (~2 billion words), ukwac corpus, and the 2009 Wikipedia dump (~ 800 million tokens).

**Table 3.** Metrics for teams' final concepts' creativity and design team behaviors.

|         | Final concepts' creativity | Design team behaviors |                        |                   |                                   |
|---------|----------------------------|-----------------------|------------------------|-------------------|-----------------------------------|
|         | SemDis                     | Fluency slope         | Evaluation process (%) | Collaboration (%) | Problem solution co-evolution (%) |
| Average | 0.59                       | 0.36                  | 14.6                   | 31.7              | 15.3                              |
| SD      | 0.05                       | 0.05                  | 5.1                    | 5.1               | 3.7                               |

The next section explores to what extent these behaviors impact their final concept's measured creativity.

### **Effect of team behavior on design idea creativity as measured by SemDis**

#### **Design idea fluency during a design session positively correlates with idea creativity**

Hypothesis H1: fluency positively correlates with design idea creativity as measured by SemDis was not confirmed. The general trend shows that teams producing new ideas with a higher frequency generated more creative ideas but there is only a weak correlation between those two metrics,  $R^2 = .13$ ,  $p = .6$  (Figure 2).

#### **More evaluation does not impact the creativity of ideas**

The second hypothesis (H2): evaluation processes positively correlate with design idea creativity was not confirmed,  $R^2 = .02$ ,  $p = .9$ . This implies that teams with more evaluation design process did not generate more creative ideas. No trend appears between idea creativity calculated with SemDis scores and the distribution of

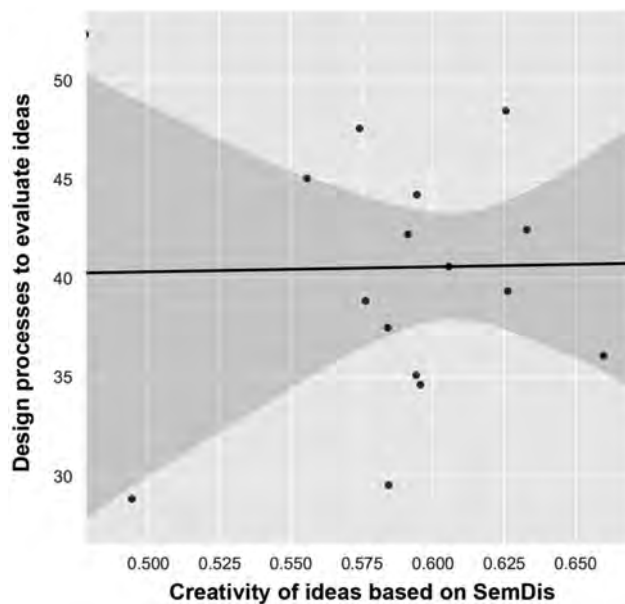
processes to evaluate ideas as illustrated in Figure 3. These results suggest that engaging more cognitive focus on evaluating ideas has little effect on the novelty of the final design.

#### **Collaborative behaviors of design teams do not affect creative ideation**

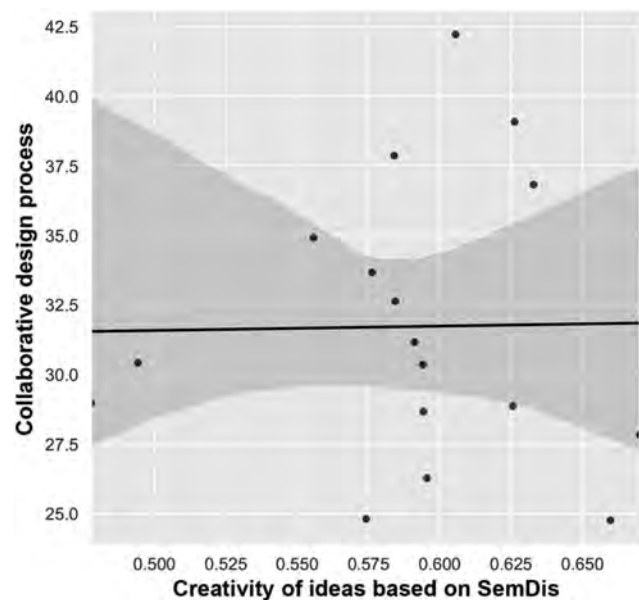
The third hypothesis 3 (H3): design collaborations positively correlate with design idea creativity is not confirmed,  $R^2 = .02$ ,  $p = .9$ . In this cohort, no trend appeared between collaborations and the creativity of design ideas (Figure 4).

#### **More co-evolutions of problem-solution spaces does not benefit creative ideation**

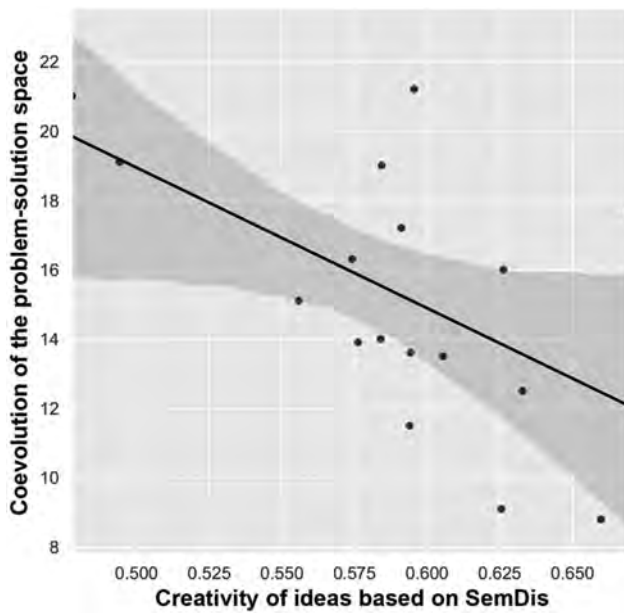
The fourth hypothesis (H4): co-evolutions of the design problem-solution space positively correlate with design creative ideas was not confirmed. The normalized distribution of PS co-evolution is negatively correlated with the creativity of the final concept ( $R^2 = -.54$ ,  $p = .03$ ). The correlation is significant and the trend appears on the graph in Figure 5. Such teams also generated final concepts assessed as less novel, as their



**Figure 3.** Design behavior *evaluation* plotted against SemDis measurement.



**Figure 4.** Design behavior *collaboration* plotted against SemDis measurement.



**Figure 5.** Design behavior *co-evolution* plotted against SemDis measurement.

SemDis scores are lower than teams with more PS co-evolution episodes.

## Discussion

In this paper, we explored different metrics from the design research community based on design protocols to gain insights on the effect of team behaviors on design idea creativity. The fluency of design ideas tends to correlate positively with idea creativity in our dataset. The ability of teams to generate new ideas was the only behavior that positively correlated with the creativity of the team's final concept as measured by SemDis. Design teams' evaluation activities did not have an effect on idea creativity, nor did design collaboration. The most unexpected finding was that teams engaging in more navigation between the problem and solution spaces scored worst on the idea creativity score. From these results, it appears that none of the team design behaviors identified and measured are proxies to predict a creative outcome that correlate with the psychology measure using SemDis.

### *Idea fluency, evaluation of ideas, and idea creativity*

In the literature, idea creativity tends to be associated with idea fluency (Shah, Smith, & Vargas-Hernandez, 2003). In this dataset, teams with a higher idea creativity rating (SemDis) tend to produce more new ideas.

Another expectation was that more cognitive focus on evaluating ideas generated by the team would lead to

a more creative outcome. The results from this cohort of 57 designers did not support this hypothesis. No trend was found between focusing on evaluation and idea creativity of the final concept (SemDis). Evaluating initial ideas while designing serves to analyze and structure the design space (Goel, 1995) which should lead to generating better design solutions. Evaluation provides a way to select the most relevant or useful ideas and to assess its originality. The results from this cohort do not align with this claim. In this study, evaluation was measured through FBS design processes as a metric for cognitive focus to evaluate all types of ideas, novel or not. More granularity (evaluation of novel ideas) in our analysis might show different correlation between idea creativity and this type of design process.

### *Team collaboration and idea creativity*

Design collaboration's effect on design creativity is unclear. This reflects previous findings in collaborative design research that highlight an inherent complexity in design teams due to social factors such as hierarchy, leadership, demographics or personality traits. In this study, team collaboration is measured through the occurrence of co-design processes. The results suggest that more than the quantity of co-design processes, their quality could be a more relevant predictor of creativity. More interactions could indicate a convergence on an idea or could signify increasing conflicts between team members. Paletz et al. (2017) suggest that how teams are able to handle social micro-conflicts impact the team's success. Social interactions and team cohesion could have a moderating effect on the relationship between the amount of collaboration and the outcome of the team's design process.

Apart from team social interactions, team composition, i.e., members' backgrounds, could also have had a mediating effect on the relationship between team collaboration and a team's creativity. In this study, some teams were homogeneous, implying that all team members had a similar discipline while other teams were composed of members from different disciplines (e.g., team 5 is composed of a safety engineer, a mechanical designer and a manufacturing engineer). A more discipline diverse team can improve creativity since the team has access to more resources (Stewart, 2006). However, a diverse skill set within a team could hinder its process as integrating different ideas and perspectives can be challenging. The homogeneity of a team could reduce social conflicts, hence improve the team performance (Stewart, 2006), although such teams might frame design problems in a similar way and

will be less likely to offer a wider set of alternative solutions (Paletz et al., 2019).

As discussed above, some characteristics of teams impact the team's performance and creativity. In this study, the focus was on design cognition analyzed through the occurrence of co-design processes. The results are mitigated when analyzing the relationship between creativity and how collaborative team members were. In future work, we will include more team characteristics as predictors of creative outcome in the design process to assess to what extent they affect teams' creativity.

### ***Co-evolution of the problem-solution space and idea creativity***

Contrary to our expectation, more cognitive focus on problem-solution space co-evolution episodes tended to correlate negatively with the SemDis creativity metric. It accords with related results from another empirical research that explored to what extent cognitive focus by design teams on problem understanding (cognitive actions situated in the problem space) or problem solving (cognitive actions situated in the solution space) relate to the creativity of solutions (Chulvi, Sonseca, Mulet, & Chakrabarti, 2012). In their study, Chulvi, Sonseca, Mulet, and Chakrabarti (2012) found no significant correlation between creativity of solutions and the time spent in either the problem or the solution space during a design task.

Previous research has emphasized the importance of co-evolution in creative design thinking (Crilly & Moroşanu Firth, 2019; Dorst, 2019; Dorst & Cross, 2001; Maher & Poon, 1996). Finding a good match between design problem requirements and a design solution translate to a "Aha!" moment for designers, usually equated to a creative breakthrough (Akin & Akin, 1996). The results from this study suggest that a high number of co-evolution episodes is not a prerequisite for creativity. On the contrary, design teams that engaged in fewer co-evolution episodes tended to produce a more novel final concept, and experienced a higher ideas fluency. A possible explanation is that quality over quantity is key for problem-solution co-evolution episodes in team creative thinking. In previous empirical studies, the co-evolution of the problem-solution space was defined as a characteristic of creative design (Crilly & Moroşanu Firth, 2019; Dorst & Cross, 2001). It suggests that iterating between the problem and the solution spaces through framing and reframing is a necessary step, without qualifying to what extent the number of processes relates to creative design. Nevertheless, these results are to be taken with care as they are limited to

a single study of 19 teams. A more detailed quantitative analysis supplemented by a semantic analysis of each co-evolution episode will provide more information on the content of these episodes that can be used to elucidate these findings. It could clarify the role of problem-solution co-evolution in team design creativity and will be explored in future research.

### **Conclusion**

In this paper, we explored to what extent creativity process metrics from design research correlate with those from psychology, in particular the psychometric measure SemDis. Nineteen teams of three designers were given an hour-long design task to generate solutions for a personal assistant and entertainment system for the future. At the end of the design session, teams were asked to verbally describe their final designs. Each team's creativity was measured through the semantic distance assessment, using SemDis, of the verbal description of their final proposed design. Four team design behaviors were analyzed as predictors of creative outcomes: idea fluency, focus on evaluating ideas, team collaboration through co-design processes and problem-solution co-evolution episodes. Team idea fluency tends to positively correlate with teams' final concept creativity (although not significantly), which aligns with previous general findings suggesting that more ideas lead to more creativity. None of the other team design behaviors predict the final concept creativity suggesting that they are not relevant proxies to assess creative outcome or highlighting SemDis's limitation to capture design creativity.

The effect of team collaboration on creativity showed no specific trend. Co-designing is affected by social characteristics like team members interactions, leadership within the team, team composition, amongst others (Paletz et al., 2019; Stewart, 2006). This study did not measure these characteristics as our focus remained on collaborative cognitive processes between team members. A more holistic approach, including cognition and social behaviors, when analyzing design teams in a naturalistic environment could provide further knowledge to understand how creativity in design teams arise.

Unexpectedly, the results show that the frequency of problem-solution co-evolution episodes correlates negatively with idea creativity. This suggests that when teams spent more time on co-evolution episodes, their final concept as assessed through SemDis is less creative. These results are surprising as the current assumption in the design research

community is that co-evolution is a prerequisite for creativity (Dorst & Cross, 2001; Wiltschnig et al., 2013).

These results failed to support the hypotheses concerning correlations between design process measures and the psychometric creativity measure using SemDis. There is a number of potential reasons for this.

- The creativity of the outcome was based on the novelty measure of SemDis. It is possible that SemDis is not an adequate measure in the design domain. hence, the lack of correlations.
- Contrary to the intuition in the design research community, it may be that these design processes measures are not good predictors of creative outcomes.
- The experiment set up had the participants design for a period and at the end of that period they were asked to describe their proposed design verbally. It may be that there is a disconnect between the design processes and the verbal descriptions of their designs. SemDis was measuring the verbal descriptions and the design processes related to the acts of designing.

In order to resolve these questions future research will measure the creativity of the final designs by using the Consensual Assessment Technique (Amabile, 1982) on the sketches of the final designs to produce a ground truth against which correlations for both processes and SemDis will be assessed. CAT to determine whether human assessment produces different results in designs. Additionally, we will run the verbalizations that occurred during the design activities through SemDis to determine whether the hypotheses have support using this measurement.

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