

Polysemy in Design Review Conversations

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***Abstract:** This paper examines the role of polysemy, defined as the quality of having multiple meanings, in design review conversations. It examines the polysemy, particularly of nouns, involved in a dataset of design review conversations with reference to design ideas. The purpose is to determine whether polysemy is related to successful development of design ideas and more creative design outcomes. The results show that the polysemy of nouns involved in the conversations of the finally developed, successful, design ideas exceeds in the most cases the average polysemy involved in the conversations pertaining to the unsuccessful design ideas. Furthermore, the polysemy of these nouns is linked to high overall creativity of the design idea. The paper concludes by discussing issues and directions for further investigation of polysemy.*

Keywords: polysemy, multiplicity, developed design concept, creativity, viewpoints on design, verbal protocol

1. Introduction

Polysemy, defined as the quality of having multiple meanings, is a multifaceted topic in research. It has been seen as problematic for structural accounts of meaning. However, polysemy is considered a necessary consequence of the human ability to think flexibly (Deane, 1988). Thus, polysemy can be considered to be related to design thinking and designing in general. However, few studies have examined polysemy in relation to design thinking (Yamamoto et al., 2009; Taura et al., 2012; Junaidy & Nagai, 2013). To fill this gap, the present study further investigates the role of polysemy in design thinking, particularly in design review conversations. In the following subsections, we introduce existing theories about polysemy and its possible relationships with design and design thinking. In particular, we try to review and summarize different views about polysemy, compare it with to other connections between words and their meanings, and examine how it relates to design and design thinking.

1.1 Polysemy in cognition in design

In the field of cognitive linguistics, polysemy is a significant topic, with research focusing on different kinds of polysemy and their role in language and cognition, fields which are closely related to design. Fauconnier and Turner (2003) have discussed the power of polysemy as meaning potential. They have also pointed out that the operation of polysemous concepts is a major cognitive resource for creativity in many of its manifestations, and argue that polysemy is also a symptom of the way in which various cognitive operations allow for creativity at many levels. However, they point out that most polysemy is invisible.

1.2 Polysemy and flexibility

Polysemy also has been seen as “an essential manifestation of the flexibility, adaptability, and richness in meaning potential” (Fauconnier and Turner, 2003). In particular, existing words are employed to express new meanings that arise in conceptual blending (conceptual integration, where elements—concepts—are blended in a subconscious process). Combinations of inappropriate inputs become meaningful in the output. The authors also discuss the noticeability of polysemy. Often unrecognized, polysemy is product of conceptual integration. Flexibility of thinking is closely related to various phenomena associated with designing and design thinking (During, 1999).

In fact, the word “design” is highly polysemous itself. For example, “design” can be used in the sense of “designing,” “plan,” “blueprint,” “pattern,” “purpose,” or “invention.” It is self-evident that thinking about “design” allows for greater flexibility than any of these particular senses. Thus, *monosemy*—the quality of having single meaning—or *low polysemy* can be seen as phenomena with different effects on designing or design thinking from the perspective of flexibility, compared to *high polysemy*. The “monosemy” of explanations—too much explanation—is pointed out as very restricting in design (McDonnell, 2011).

To illustrate the difference between monosemy and polysemy, in Figure 1, two words with different polysemy are compared: “idea” with 5 noun senses and “concept” with 1 noun sense, where the word “idea” is supposed to allow for greater flexibility than the word “concept”.

The phenomena related to polysemy are under-researched in the field of design.

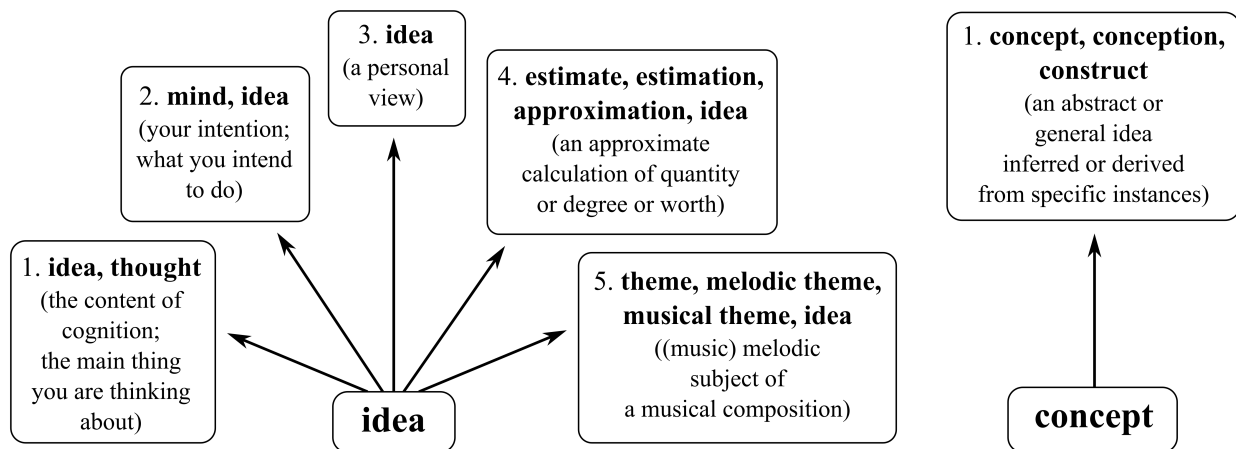


Figure 1. Polysemy of words “idea” and “concept”; explanation of the meaning is provided in parentheses (example based on WordNet 3.1)

1.3 Polysemy and other types of connections between meanings of words

Polysemy and association

A comparison of polysemy with *association*—understood as a mental connection between ideas or things, which is a more common topic in design research and creativity in general (Osborn, 1963)—reveals certain similarities between them. Certain polysemy meanings are based on associations between words. However, polysemy has a broader scope and may include not only such connections but also as other uncommon connections.

Polysemy and metaphor

Polysemy is related to the figurative language such as metaphors (Nerlich, 2003). A *metaphoric extension* occurs when the meaning of text is extended beyond its original meaning (e.g. “the place is busy”) on the basis of similarity. Conceptual metaphors appear to qualify as a special type of regular polysemy (Deane, 1988). Metaphors are the primary source of polysemy as they allow words with specific meanings to have additional (related) meanings (Gentner and Bowdle, 2001).

Polysemy and synonymy

Words represent concepts in human language, but the mapping from words to concepts is many-to-many. In other words, one concept may be represented with many different words (*synonymy*) and one word may represent many different concepts (polysemy) (Ozcan and Aslandogan, 2004).

Polysemy and ambiguity

Ambiguity (different from vagueness) is another important topic for design research and is related to the meaning of words. There are different kinds of ambiguities related to words and their meanings. Polysemy is different from homonymy (a common type of ambiguity). For example, polysemy words involve a number of related meanings (e.g., “twist” as “turn,” “spin,” or “bend”). Homonyms are accidentally similar words with no relation to each other (e.g. “bow” as “knot”; and “bow” as “bow down”). However, there is no strict distinction between polysemy and ambiguity.

The ambiguity rule—design thinkers must preserve ambiguity—has been discussed as one of the rules of design thinking (Meinel and Leifer, 2010).

In general, ambiguity in design is present in not only words and conversations but also various design means and media, such as sketches. Ambiguity enables the multiplicity of interpretations that are the foundation of creative thought (Tversky, 2010). It enables the kinds of reinterpretations that underlie much creative thought.

1.4 Polysemy and other characteristics of design thinking

Product meaning

Polysemy also has been discussed as the *meaning* of products. For example, polysemy is one of the three essential characteristics that are incorporated by the object’s meaning (contextual sensitivity and consensus being the other two) (Chapman, 2005, p. 39). Polysemy implies that an object can mean many things; for example, baking soda could be considered a refrigerator deodorizer, a dentifrice, or an antacid.

On a structural level, Stern (1989) has discussed polysemy of meaning in terms of interpretation that involves complex processing tasks on the part of consumers. Furthermore, the meaning is polysemic and involves the interaction of design and the recipient (Buckley, 1986). The meaning is encoded in the design and further decoded by consumers according their own cultural codes.

Product semantics

In product *semantics*, instead of favoring one-to-one relationships, polysemy is recognized as normal, not an undesirable exception. Meanings are found in the multitude of contexts that a person can construct for something to make sense. Contexts are seen as disambiguating agents, and meanings are sought in a multitude of contexts (Krippendorff, 1992). Furthermore, product

semantics deals with polysemic meanings on the basis of the notion of “context of use” (Markussen, 2008). It is difficult to determine the core meaning of a word (Krippendorff, 1993). Polysemous words can assume a range of roles in different situations.

In summary, product semantics views polysemy on the basis of context of use and discovery of meanings.

1.5 Representations for design and natural language processing for design

Polysemy of words is generally regarded as a side effect in systematic design or even an obstacle to systematic and knowledge-based representations in design (e.g., in computer-aided design systems). In knowledge-based representations, polysemy is regarded as an issue connected with disambiguation (identification of one particular meaning) (Setchi et al., 2011).

Natural language processing addresses the apparent need for disambiguation of meanings; thus, it is also concerned with polysemy.

1.6 Early stage of design

Unlike the previous account of polysemy as an obstacle, for the early stage of design, polysemy represents an opportunity for developing more original design ideas; thus, it is related to creativity.

Previous studies investigated polysemy in the early stage of design (design idea generation). They found a relationship between the average polysemy of design ideas and originality rating of the ideas in a concept synthesis task (Taura et al., 2012, Taura and Nagai, 2013). In order to investigate the concept generation process, the route between the base concepts and design idea features was investigated. The route was represented as connected words; the average polysemy of resultant design idea features was correlated with the originality rating of the design ideas (Taura et al., 2012).

1.7 Summary of investigations on polysemy

Most of the aforementioned studies have investigated polysemy at a fundamental level, focusing on its general characteristics in human activities. However, until recently, there has not been much focus on polysemy from the perspective of designing and design thinking. One of the few examples from the field is a recent study that found polysemy to be related to the originality of generated design ideas in the early stage of design (Taura et al., 2012).

In particular, the relation of polysemy to **teaching design thinking** has not been clarified, and the effect of polysemy on the result of the design review conversations remains an **open issue**. This issue relates to the understanding of the involvement of polysemy in design review conversations and possible implications of polysemy as a tool for teaching and enhancing design thinking. This study attempts to shed light on this topic.

2. Research question

This study aims to provide insights into the role of polysemy in design thinking, especially in the context of design conversations, development of design ideas, generation of original design ideas, and design creativity.

The research question is as follows:

- Is polysemy involved in design review conversations connected to successful development of design ideas and more creative design outcomes?

An additional question could be as follows: are there characteristics of (factors related to) polysemy that are evident in the process of design thinking and design review conversations?

3. Theoretical framework

We employ a theoretical framework based on approaches to *polysemy* on the micro and macro levels.

In particular, we first **define** the following terms in the micro-level approach.

- *Concept about design*: a concept (word) that is used to describe or explain the reasoning behind the design.
- *Polysemy of concepts (about design)*: the quality of having multiple meanings for the different concepts about design. Polysemy of concepts is interpreted as the (average) polysemy of the words used to express the impressions from the product (polysemy at the micro level).

Then, we then **define** the following terms in the macro-level approach.

- *Viewpoint on design*: attitude towards the design or meaning of the design (e.g., different contexts, functions, or interpretations of the design).
- *Polysemy of viewpoints (on design)*: the quality of having multiple attitudes towards the design or meanings of the design. Polysemy of viewpoints (polysemy at the macro-level) refers to all the different interpretations of the product by the user or designer, in terms of different contexts, functions, uses, applications or significances for the user or designer. That is, a meaning is a distinct interpretation of an product in terms of context, function, use, application, or significance for the user or designer.

The *concept about design* and *polysemy of concepts* are part of the micro-level approach to *polysemy*, while *viewpoint on design* and *polysemy of viewpoints* are part of the macro-level approach to *polysemy*.

Furthermore, we are particularly interested in the characteristics of *polysemy*, specifically the *polysemy of concepts*, concerning design review conversations.

4. Methods and analysis approach

We focus on design review conversations and slides that describe the design idea output. To clarify the aforementioned research question, we developed a method to identify and evaluate polysemy involved in design review conversations and the creativity of the design ideas that were the outcomes of these conversations.

4.1 Target of analysis

Our target of analysis is the dataset of “Industrial Design (Graduate)” design review conversations of 10th Design Thinking Research Symposium (DTRS10) (Adams & Siddiqui, 2013), obtained in Public University, graduate industrial design course. This dataset is derived from a semester-long industrial design course. It contains data from 6 graduate students: Allison, Eva, Julian, Mylie, Sydney, and Walter. The primary coach is the course instructor Simon; there here are two stakeholders (Chuck and Peter, clients) involved in the conversations.

The design brief given to the graduate students in this dataset is “Outside the Laundry Room” (Adams & Siddiqui, 2013). The client from global home appliance industry wanted to look

outside of an internal definition of “laundry”, defined as machines for washing and drying clothes. Consumers define the “laundry” process as much broader than simply washing and drying such as gathering and sorting clothes, and folding and putting away clothes. The client is exploring the tension between these two definitions to look for disruptive innovation opportunities.

The main analysis objects are the transcripts of design review conversation and slides with the design ideas from the Concept Review, Client Review, and Concept Reduction Review steps (Table 1).

The choice outlined in Table 1 is based on the following considerations:

- “Industrial Design (Graduate)” dataset is based on an open design brief targeting disruptive innovation. It was chosen because of the numerous distinct and clearly discussed (described and demonstrated) ideas that were generated. It clearly shows the evolution of ideas with possibly more identifiable instances of creativity, broad conceptual ideation, and intensive critiques.
- D-search conversation is omitted because of its general nature (i.e., it is without identifiable design ideas).
- Allison was omitted because of a lack of intermediate Client Review slides (all design ideas).
- Design ideas are discussed on the basis of slides from Client Review with the addition of one alternative idea of Julian that was developed based on the Concept Reduction Review and demonstrated in the slides of the Final Review.

Furthermore, our particular focus in the conversations is **nouns** because we consider that nouns are related to the designed product and the thought process involved in the design process of the new product.

Table 1. Target of analysis in the dataset (chosen data is marked with “v” and a note, data omitted in this analysis with “x,” and unavailable data with “-”).

Graduate student	Steps of the design review conversations				
	D-search Review	Concept Review	Client Review (using phone)	Concept Reduction Review	Final Review
	Modalities that were focused on in analysis				
	x	Speech, Written/Artifact (slides)	Speech, Written/Artifact (slides)	Speech, Written/Artifact (slides)	Written/Artifact (slides)
Allison	x	x	-	-	x
Eva	x	v (transcript)	v (transcript and slides)	-	x
Julian	x	-	v (transcript and slides)	v (transcript)	v (slides of idea from the previous review)

Mylie	x	v (transcript)	v (transcript and slides)	-	x
Sydney	x	v (transcript)	v (transcript and slides)	-	x
Walter	-	v (transcript)	v (transcript and slides)	v (transcript)	x

4.2 Outline of the methods and analysis approach

Previous research on the thought process during the early stages of design applied various methods to analyze concepts as words and meanings in the generation of design ideas (Georgiev et al., 2010, Taura et al., 2012). We further build upon and develop these methods.

Analysis method of polysemy on micro-level

As primary focus of the micro-level analysis, we consider nouns. For the analysis, we apply the following steps:

Step 1. Preparation of the data.

The transcript was cleaned of indications of non-verbal expressions such as “[Laughter],” speaker names such as “*Speaker:*” and all the time stamps.

Step 2. Identification of the part-of-speech of all words.

All the transcripts were parsed with Natural Language Toolkit (Natural Language Toolkit NLTK 3.0; Bird et al., 2009). This parsing process generated a list of all the words in the transcripts with identified parts-of-speech as used in the sentences of the transcript. The final output was all words identified as nouns.

Step 3. Identification of the number of noun meanings.

We employed the lexical database WordNet (WordNet 3.1; Fellbaum, 1998) and Natural Language Toolkit to identify the number of noun senses of the nouns outputted in the previous step. This software allowed us to identify different word senses (*analyze concepts about design and polysemy of concepts*). After this step, all identified nouns were listed with the number of their senses found in WordNet.

Step 4. Calculation of the average polysemy of nouns.

We calculated the average polysemy of all identified nouns as per conversation or time period. Table 2 shows an example of the micro-level analysis.

Table 2. Example of a micro-level analysis of polysemy

Transcript detail	Nouns (Step 2)	Polysemy of nouns (senses identified with WordNet 3.1) (Step 3)	Parameter (Step 4)
<i>Simon, instructor:</i> ... I see someone sitting in a – in a living room underneath a tree.	someone	1	Average polysemy of all identified nouns from Step 2:
	living	4	
	room	4	
<i>Mylie, graduate student:</i> That’s the point.	tree	3	
<i>Simon, instructor:</i> That’s the point.	point	26	
	point	26	

So it's, it's, it's intentionally playing with this idea of being somewhere different, like, like is it the outside living room? ... [Concept Review, Mylie, graduate student, see Table 1 for details]	idea	5	8.875
	outside	2	
	...		

Method for evaluation of creativity

Creativity of design ideas was evaluated in terms of “originality” (whether the idea is novel) and “practicality” (whether the idea is achievable and feasible), which were each rated on 5-point scales. “Originality” was chosen instead of “novelty,” which has a more general interpretation. These two criteria were chosen on the basis of previous research by Finke et al. (1992, p. 67). However, it should be noted that more comprehensive evaluations of creativity exist (for further discussion on evaluation criteria, see Verhaegen et al., 2013).

Analysis method of polysemy on macro-level

For such analysis, a procedure to identify predefined keywords can be developed (Table 3). These keywords can be used to detect when a *viewpoint on design* changed (e.g., keywords referring to *functions, context, situation, purpose*, etc.) in the student’s and instructor’s individual reasoning about and descriptions of a design, as found in the transcripts. This analysis can output expressions that are identified as related to the changes in viewpoints on design.

Table 3. Example of a macro-level analysis of polysemy

Transcript detail	Identified as	Analysis
(1) “...it works like a vacuum that should be appearing at...public places...like a public restroom and ...just like...what you use...with a hand dryer in public place. It cleans out dirt and smell on suits that cannot be washed often or cannot be washed by water.” (2) “...wear on it and it can clean your out wear by using ultrasound vibration to, uh, to wipe out dirt and, yeah, to wipe out dirt and make, make the out wear last longer.” [Client Review, Julian, graduate student]	(1) Design description (2) Design process reasoning	In (1) keyword “places” refers to the “ <i>context</i> ” in which the design is placed and “cleans” to its “ <i>purpose</i> ,” while in (2) keyword “using” refers to “ <i>function</i> .”

5. Analysis and results

5.1 Analysis of polysemy on micro-level

The research question was investigated based on the above micro-level analysis. First, the design review conversations were analyzed to identify portions of the transcripts corresponding to each of the design ideas. A total of 26 design ideas were identified for the five graduate students included in the analysis (Eva, Julian, Mylie, Sydney, and Walter). For example, design idea 41 of Sydney was identified as discussed from the whole conversation in the Concept Review step and two distinct parts of the Client Review step—from the opening to 57 seconds and from 4.46 to 6.38; however, it was not discussed in the Concept Reduction step (Table 4; see Figure 2 for slide and transcript).

Table 4. Example of time of design review conversations about one idea during different steps of the conversations

Graduate student	Idea number	Concept Review step	Client Review step		Concept Reduction step
			Identified conversation parts in the step [mm.ss]		
			1	2	
Sydney	41	Whole conversation	0.00 ~ 0.57	4.46 ~ 6.38	-



Sydney, graduate student: Oh, okay. And then 41 to 45. Hello?

Peter, client: Yes, we're here.

Sydney, graduate student: Yeah. Uh, the first one is 41. It's, uh, hanger and, uh, according to our dsearch, a lot of people don't like use hanger because they think it's very difficult to use and it will cost lot of time. So I design this hanger and, uh, it's, uh, inspired by the scissors. Uh, you can see the little comic behind in the left. Uh, the, the hanger can change the shape in different situation. Uh, it is – it is –

Peter, client: That's, that's a good one.

Sydney, graduate student: Uh.

Peter, client: I get it. ...

Figure 2. Slide of idea number 41 and transcript of Client Review step (part 1 in Table 4)

Second, all nouns were identified using the previously outlined method of analysis (Table 2). The average polysemy of all identified nouns was calculated for each design idea; in addition, the average polysemy of each step/part was also calculated (Table 5 shows average polysemy of each step/part and Table 6 shows the average polysemy of all identified nouns).

In general, each graduate student generated five design ideas from which one idea was finally developed (based on the Written/Artifact (slides) provided in the dataset [Adams, 2013]). One exception was idea 14A in Tables 5 and 6, which was developed as an alternative of idea 14 in the Concept Reduction step. Idea 14A was detached here as it has distinct features compared to idea 14 and was extensively discussed in design review conversations during the Concept Reduction step.

In order to account for the different number of nouns in each design idea, a weighted average W_{ave} of the polysemy of nouns was calculated as follows:

$$W_{ave} = \frac{\sum_{i=1}^k n_i p_i}{\sum_{i=1}^k n_i}$$

where k is the number of non-successful design ideas per graduate student (4 or 5); n_i is the number of identified nouns in all the design review conversations for the i -th design idea; and p_i is the average polysemy of all identified nouns for the i -th design idea.

The two-sample t-test assuming equal variances performed between the average polysemy of all identified nouns and finally developed concept (“y”/“n”; Tables 5 and 6) showed no significant

correlations for the design ideas for Eva, Julian, Mylie, and Sydney; however, it is significant for Walter ($p=0.006<0.01$; 4 observations for “n” and 1 observation for “y”).

Table 5. Evaluation of noun polysemy of steps of design conversations

Graduate student	Idea number	Noun polysemy evaluation of conversations (steps)								
		Concept Review step	Client Review step				Concept Reduction step			
			Identified conversation parts in the step				Identified conversation parts in the step			
			1	2	3	4	1	2	3	4
Eva	16	5.20	2.54	5.90	-	-	-	-	-	-
	17	-	5.44	4.51	-	-	-	-	-	-
	18	-	4.19		-	-	-	-	-	-
	19	-	4.45		-	-	-	-	-	-
	20	-	5.36	4.51	-	-	-	-	-	-
Julian	11	-	6.20	4.50	-	-	-	-	-	-
	12	-	5.63	5.40	-	-	-	-	-	-
	13	-	5.53	5.41	-	-	3.57	4.65	4.47	-
	14	-	2.61	1.00	4.91	-	5.17	-	-	-
	14A	-	-	-	-	-	4.85	3.43	4.49	4.38
	15	-	4.74	3.42	-	-	-	-	-	-
Mylie	1	-	4.31	4.23	-	-	-	-	-	-
	2	-	4.62	5.41	-	-	-	-	-	-
	3	-	4.76	-	-	-	-	-	-	-
	4	-	6.09	-	-	-	-	-	-	-
	5	5.29	3.98	4.37	-	-	-	-	-	-
Sydney	41	4.97	3.83	4.65	-	-	-	-	-	-
	42	-	4.13	-	-	-	-	-	-	-
	43	-	3.25	-	-	-	-	-	-	-
	44	-	6.45	-	-	-	-	-	-	-
	45	-	3.89	5.02	-	-	-	-	-	-
Walter	6	6.66	5.54	4.52	5.81	-	4.11	4.50	-	-
	7	3.81	5.12	3.90	-	-	-	-	-	-
	8	3.81	4.79	5.73	4.57	5.81	3.33	-	-	-
	9	3.76	4.11	-	-	-	-	-	-	-
	10	4.32	4.14	-	-	-	-	-	-	-

Table 6. Evaluation of overall noun polysemy and developed concepts

Graduate student	Idea number	Overall noun polysemy evaluation of conversations			Finally developed concept (y/n)
		Number of all identified nouns	Average polysemy of all identified nouns	Weighted average polysemy	
Eva	16	223	4.79	4.74	n
	17	78	4.97		n
	18	42	4.19		n
	19	22	4.45		n
	20	145	5.13	5.13	y
Julian	11	29	5.38	4.67 (includes *)	n
	12	31	5.52		n
	13	136	4.72		n
	14	49	3.86		n
	14A	202	4.47	4.47	y
	15	31	4.23	*	n
Mylie	1	135	4.27	4.75	n
	2	72	4.81		n
	3	54	4.76		n
	4	44	6.09		n
	5	847	5.13	5.13	y
Sydney	41	173	4.79	4.79	y
	42	24	4.13	4.74	n
	43	16	3.25		n
	44	22	6.45		n
	45	80	4.75		n
Walter	6	521	5.26	5.26	y
	7	169	4.21	4.28	n
	8	409	4.34		n
	9	73	4.03		n
	10	319	4.29		n

5.2 Creativity evaluation of the design ideas

Creativity was evaluated by four judges using a 5-point scale; the criteria were originality and practicality. The results of this evaluation are shown in Table 7. The last column “Creativity (Originality & Practicality)” is the average of the originality and practicality ratings.

The average polysemy of all identified nouns was compared to the average originality, practicality, and creativity ratings for each graduate student.

Table 7. Noun polysemy and creativity evaluation

Graduate student	Idea number	Summary of noun polysemy evaluation		Average creativity evaluation		
		Average polysemy of all identified nouns	Weighted average polysemy	Originality	Practicality	Creativity (Originality & Practicality)
Eva	16	4.79	4.74	3.25	2.65	2.95
	17	4.97		2.75	4.15	3.45
	18	4.19		4.25	2.85	3.55
	19	4.45		2.75	2.95	2.85
	20	5.13	5.13	3.25	3.45	3.35
Julian	11	5.38	4.67 (includes *)	3.75	3.95	3.85
	12	5.52		4.25	2.65	3.45
	13	4.72		3.50	3.70	3.60
	14	3.86		3.00	4.00	3.50
	14A	4.47	4.47	4.00	3.40	3.70
	15	4.23	*	4.00	2.80	3.40
Mylie	1	4.27	4.75	2.50	3.30	2.90
	2	4.81		3.50	3.50	3.50
	3	4.76		2.50	3.50	3.00
	4	6.09		3.75	2.55	3.15
	5	5.13	5.13	3.75	4.15	3.95
Sydney	41	4.79	4.79	3.00	4.40	3.70
	42	4.13	4.74	3.75	3.75	3.75
	43	3.25		3.25	3.25	3.25
	44	6.45		2.50	3.70	3.10
	45	4.75		2.50	3.30	2.90
Walter	6	5.26	5.26	4.00	3.20	3.60
	7	4.21	4.28	4.00	2.80	3.40
	8	4.34		3.00	3.80	3.40
	9	4.03		3.75	2.95	3.35
	10	4.29		3.25	2.45	2.85

Spearman rank correlation analysis (Spearman’s rho) between the average polysemy of all identified nouns and originality, practicality, and creativity for each graduate student revealed no significant correlations, except for Mylie (between average polysemy and originality ($r=0.949$, $p=0.014<0.05$)). However, the final successfully developed design ideas were among those that received the highest ratings.

5.3 Ongoing macro-level analysis of polysemy

The macro-level analysis is ongoing. As discussed in the methodology section, the analysis is focused on identifying a set of keywords referring to functions, context, situation, purpose in the

student's and instructor's individual reasoning, and design descriptions found in the design review conversations. The analysis aims to identify changes in viewpoints on design and polysemy.

6. Discussion

6.1 General discussion

Among the cases of graduate students in Tables 5 and 6, four show that the value of the average polysemy of all identified nouns for finally developed concept (indicated by “y” in the last column) is greater than the average polysemy and weighted average polysemy for concepts that were not developed until the final stage (indicated by “n” in the last column). The concepts that were not developed until the final stage failed during the design process and design review conversations. A design idea whose discussion was characterized by a higher polysemy of nouns tended to be successfully developed.

Furthermore, ideas with high creativity were the outcome of more polysemous design conversations. This was observed in the case when the individual design ideas of graduate students are compared. Polysemous words have a higher increased probability for combination, which may lead to successful design concept generation (Taura and Nagai, 2013).

The main **finding** can be summarized as follows. There is a tendency for ideas generated in design review conversations characterized with higher polysemy to be successfully developed and to exhibit high overall creativity. This result suggests that polysemy contributes to the successful development of design ideas. This finding has possible implications for research on and teaching of design thinking, and its implications are discussed in detail in Section 7 of this paper.

6.2 Limitations

The analysis has several limitations. First, English was not the native language of some of the participants. This may have influenced their speech and consequently the analysis of polysemy. In fact, some of these graduate students had relatively short design review conversations for some of their ideas; for example, conversations on ideas 42, 43 and 44 include only 24, 16 and 22 identified nouns. To partially address this limitation, we introduced the weighted average polysemy evaluation (Tables 5, 6 and 7).

The second limitation is that the analysis used an automated method for the detection of part-of-speech and consequently noun senses. An analysis method in which these steps are manually performed or supervised may yield greater or more appropriate insights into the discussed topic or design.

Also, the current approach does not account for the intersubjectivity of meaning between the various participants in the design review conversations, which is important aspect to understand in language and meaning as a process in the conversations (Dong, 2009).

6.3 Views and interpretation of the contribution of polysemy

In this study, we are particularly interested in the unintentional aspect of communication, although the intentionality of speech acts is a characteristic of complex communication (Harnish,

1990). Polysemy can capture a characteristic of an unintentional aspect of the design review conversations. On the basis of the results, a hidden characteristic of the conversations is expected to be identified. The basis for this is that higher polysemy characterizes the design review conversations of successfully developed design ideas that exhibit high overall creativity.

Previous research suggested that more unique noun phrases used to describe design concepts in early stages of mechanical design are connected with highly evaluated design outcomes (Mabogunje and Leifer, 1997). Although unique noun phrases or polysemy of nouns can be seen as merely surface linguistic features characterizing design process, we consider that such features are indicative for hidden characteristics of the descriptions of design concepts or design review conversations, which may be important to successfully develop design ideas and generate design ideas that exhibit high overall creativity.

Considering monosemy vs. polysemy, we can examine the contribution of polysemy to design thinking. Monosemy can be regarded as definition or convergence into a single word or interpretation of a design idea, while polysemy can be interpreted as broadening or divergence into a number of meanings or design ideas.

From a practical standpoint of possible implications for teaching design thinking, design review conversations, and early stages of design, polysemy may be seen as

- Contributing diversity, hints, or clues. Here, diversity, hints, or clues may relate to creativity. For example, words with high polysemy may present more hints compared to words with lower polysemy in the designing of a product.
- Contributing to ambiguity (“un-define-ness”) and stimulating search for a meaning. Here, ambiguity may relate to originality and thus to creativity. For example, an ambiguous word may lead to a search for new interpretation and new aspect.
- Contributing relevancy to a situation and providing greater number of relevant meanings; may relate to practicality in creativity. For example, different meanings may increase number of relevant ideas.

Another direction is treating polysemy as a stimulus. Here, we focus on words with high polysemy as stimuli, rather than the words with high polysemy describing a design in a design brief, part of the description of a design idea, or communication of design ideas within a design team, etc. As already noted, if a word stimulus has high polysemy, it may lead to more diverse ideas and thus to more original and creative design ideas.

Comprehension of polysemy of a word is another important aspect. It is probable that not all meanings of a word are (immediately) comprehended by a designer. More common meanings are more likely to be comprehended, and more uncommon meanings are less likely to be comprehended by the designer. Thus, they may serve as a hint.

A suggestion can be made regarding polysemy and abstract concepts. Just by virtue of being more abstract (more general, higher in the concept hierarchy) concepts may exhibit higher polysemy. Thus, this aspect deserves further investigation.

6.4 Further work

The further task is macro-level investigation of polysemy, as discussed earlier. This may provide additional insights into the findings of the paper. This macro-level analysis may allow expanding further the framework beyond language to include the various other artifacts of designing such as sketches.

Future work also includes a more detailed investigation of the time-scale developments of individual design ideas. The particular research question here is if the polysemy in the time scale can be connected with particular features of design ideas. Such work may include investigation of polysemy in critical moments in the development of design ideas (Sonalkar et al., 2013). Of particular interest here are polysemy changes in such moments; moreover, it must be explored if polysemy is connected to the resolving of obstacles in critical moments.

Another approach may be focusing on refinement of analysis based on classification of nouns, for example, based on taxonomy classification in noun classes (Akin and Awomolo, 2014), related to objects, requirements, environment, information, etc.

7. Contributions

7.1 Advancing research on design thinking

The analysis in this study provides insights into the generation of creative design ideas and their successful development. Successfully developed design ideas may be considered as representing a “good design,” as they result from polysemous design review conversations and polysemous thought processes.

7.2 Improving design teaching and learning

The knowledge of the role of polysemy in design review conversations can be used as a teaching tool for design thinking—specifically, instruction on how to successfully develop design ideas with the help of polysemy and how to generate design ideas with greater creativity (e.g., through design briefs, design descriptions, stimuli, background information)—as well as a tool to enhance one’s own design process.

Generally, practice is seen as dynamic and complex, routinized as well as creative, not singular but pluralistic. The practice has several meanings, just as everything we live or think has multiple meanings (Adams et al., 2011, Dall’Alba, 2009). Thus, enactment of polysemy is possible natural direction in learning and practice.

8. Potential audiences for this work

The potential audiences for this study are wide ranging. In particular, the audiences could include design educators who aim to enhance their students’ successful development of design ideas and generation of creative ideas on new designs through the process of design review conversations. Other audience could include design researchers who aim at promoting a further understanding of the basic processes in design thinking.

9. Conclusion

In this paper, we examined the role of polysemy in design review conversations. We investigated polysemy, particularly that of nouns, involved in the selected dataset of design review

conversations with reference to design ideas. The results of the analysis show that, in most cases, the polysemy of nouns involved in the conversations of the finally developed and successful design ideas exceeds the average polysemy of the unsuccessful design ideas. Furthermore, the polysemy of nouns involved in the conversations can be connected with high overall creativity of design ideas. In summary, ideas generated in design review conversations characterized with higher polysemy tend to be successfully developed and to exhibit high overall creativity. These findings have implications for teaching design thinking, particularly for promoting the development of successful and creative design ideas through design review conversations.

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