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Analogies and Metaphors in Creative Design*

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In our increasingly flat and connected world, skills in innovation and creative design have emerged as key attributes for graduating engineering designers. Metaphors and analogies are commonly voiced as key tools for enhancing creative design yet little research has been performed on their relation to each other and their use within the design process. In this paper we discuss the relationship between metaphor and analogy use in the design process, with a focus on engineering education. We support our discussion with results from interviews and experiments with student designers. Our results highlight that both metaphor and analogy are spontaneously used by student designers and that metaphor dominates as the design tool for early problem-framing design phases whereas analogy dominates as a tool for concept generation. We also present an analysis of the metaphors for our understanding of design in use within Germany, the UK and Mexico. We found an 85 per cent overlap between textbook usages of metaphors in conceptual design in these countries as compared to textbooks authored in the United States, suggesting that cross-cultural differences in design understanding are relatively small in higher education. We close by presenting a design by analogy method to promote and enhance the use of analogy as a skill for graduating engineering designers.

Keywords: metaphor; analogy; creative design; idea generation; innovation processes; problem framing; design methods; design thinking; design education

INTRODUCTION

THE NATIONAL ACADEMY OF ENGINEERING (NAE) recently released two reports on the Engineer of 2020 [1, 2] that identify the 'flat world' [3] skills needed by engineers in the twenty-first century. These reports emphasize the need for engineers of the future to develop skills in practical ingenuity and creativity to differentiate them from low wage engineers on the international market. In other words, the top paid engineers will be those that are skilled in developing innovative new products and markets. This paper approaches this goal through understanding the use of metaphors and analogies in the design process and complements other approaches to fostering creativity such as those described in Teng [4] or Ogot [5]. In this context, we generally define the term metaphor as 'a figurative expression which interprets a thing or action through an implied comparison with something else; a symbol', and we generally define analogy as 'illustration of an idea by means of another familiar idea that is similar or parallel to it in some significant features' [6, 7].

Imagine the genesis of a VW Beetle automobile from an insect or the genesis of a bridge arch from the structure of a natural cave formation. Examples, such as these, abound in discussion of innovation and creative design. For example, analogies to nature or existing products and systems often assist engineers in finding innovative solutions. Figure 1 shows an innovative design for a bipolar fuel cell plate. The critical functions of the bipolar plate for current generation are distributing, guiding and dispersing a fluid over its surface. Leaves have these same functional attributes and drawing an analogy between the leaf and the fuel cell, in this case the bipolar plate, rapidly leads the engineer to make use of Nature's experience.

A widely cited design metaphor discussed in [8] tells the story of how the Canon team was inspired by the metaphor of a beer-can copier. The intent of a beer-can copier is to be as simple and inexpensive to manufacture as a beer can. The metaphor promoted the idea of keeping the copier as a shell, where the parts that are more likely to break down are allocated to the regularly replaced cartridge. In 1981 Apple promoted their new Apple computer as a bicycle for the mind [9]. More recently, Ryokai [10] and colleagues at the

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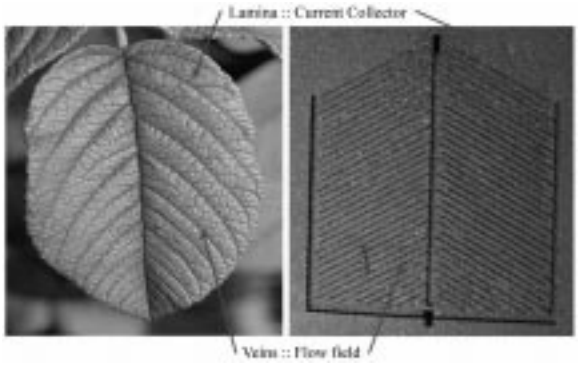

Fig. 1. Fuel cell bipolar plate design generated from an analogy to a leaf.

Fig. 2. A child uses the I/O brush [10] to choose a colour and texture from his palette: the world.

MIT Media Lab developed the metaphor The World Is A Palette in their project 'the I/O brush' (Fig. 2). The brush allows colours, textures and even movements to be captured from the world to create new types of art and a new experience for the artist.

These examples highlight just a few of the ways metaphors and analogies are used. Metaphors and analogies are also at work in branding, interface design, problem framing, communicating a common vision and enhancing concept generation. Furthermore, while traditionally metaphors were seen primarily as literary flourish, recent research has shown that metaphor usage is both more pervasive and more profound [11, 12]. Metaphors affect the way we reason about such widespread everyday concepts such as time, problems and emotions. Researchers have also argued that metaphors are fundamental in our understanding of the design process itself [13].

Figure 3 shows the example of the metaphor 'Design As Functional Analysis'. This metaphor focuses the design process on the functionality of what a product does while hiding many other important aspects such as how the user interfaces with the product and the products' aesthetics.

Despite their common usage and the similarity of metaphors and analogies, little research has been dedicated to understanding the relationship between metaphors and analogies in design and how they can enhance creativity and innovation, especially within engineering education. In this paper we seek to explore the relationship between metaphors and analogies in the design process. In particular, we investigate the use of metaphor and analogy at different stages of the design process, how they support creative design and how they are used in the educational environment. We also employ metaphor as a tool to explore cross-cultural understanding of design.

BACKGROUND

Metaphor and analogy: definitions for design

We begin by defining the relative meanings of analogies and metaphors in design. Both compare a situation in one domain with the situation in another. Gentner and Markman [14] posit that whereas the fundamental property of analogies is the relational and structural similarity, metaphors span the spectrum of relational similarity at one end, and appearance similarity at the other, Fig. 4. These definitions do describe analogy and metaphor as used within the design context, but a key dimension is missing. We suggest that the key difference is in the elements that are mapped between domains and how they are used in the design process.

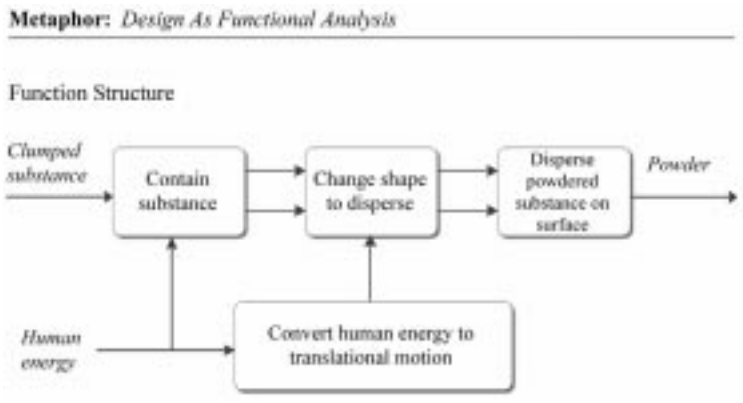

Fig. 3. 'Design As Functional Analysis' is a common design process metaphor.

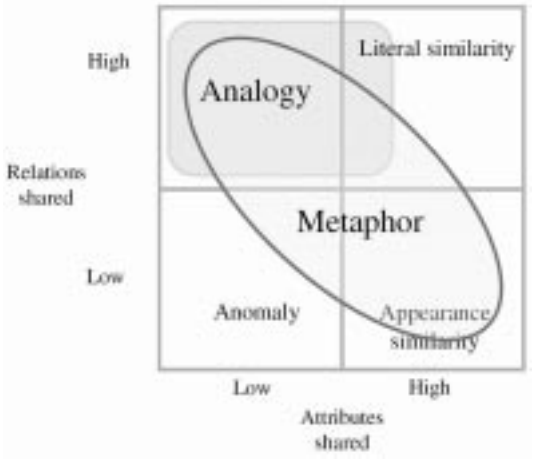

Fig. 4. Relationship between analogy and metaphor modified from Gentner and Markman [14].

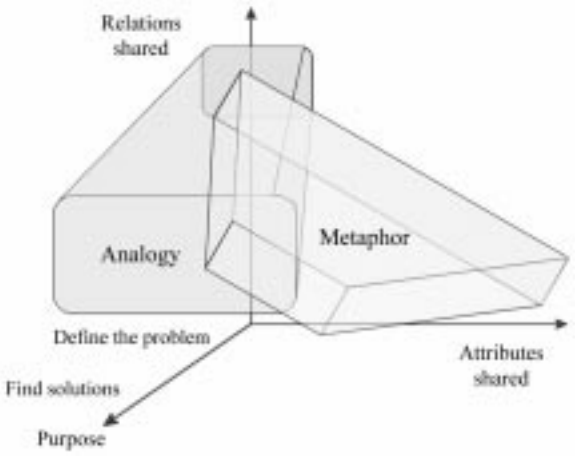

Fig. 5. Definition and relationship between analogy and metaphor as used within design.

Metaphors frame and assist the designers in defining the design problem. Metaphors are commonly used to map users' understanding, activities and reactions to a product. They help make sense of customer needs or physical attributes from the source of inspiration. Metaphors' exceptional communication ability provides meaning to a design situation; a cafeteria when seen as an oasis for its visitors becomes a different place entirely.

Analogy, in contrast, primarily maps the causal structure between the source product or system in one domain to the target design problem being solved. The causal structure includes a devices' functional solutions, geometry or component configuration. These distinctions are shown diagrammatically in Fig. 5, where the intent is to test this notion through our studies of designers and design processes.

Reasoning with metaphors and analogy

Analogies and metaphors are usually seen as a mapping between a source and a target domain (Fig. 6). The target domain is the domain to be

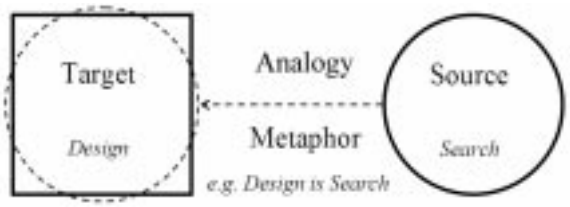

Fig. 6. Metaphors and analogies map from a source domain to a target domain.

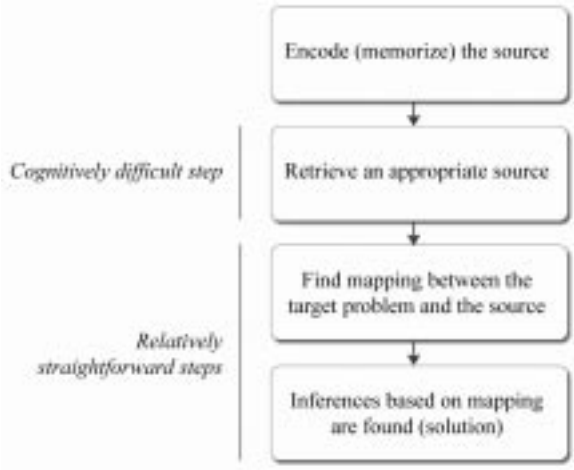

Fig. 7. Process steps in human reasoning by metaphor and analogy [15–19].

understood. For example, in the Apple 'Bicycle for the mind' example, the target domain is the Apple computer, and the source domain is the better known domain of bicycles and travel. When we use this source domain, we evoke a travel frame, and we are able to tap into our knowledge about bicycles and travel to enrich our understanding of the Apple computer. For instance, a bicycle helps the body travel further and faster than before with less effort. By implication, the Apple computer will allow us to perform more tasks, faster and more in-depth than before with less effort.

Understanding the cognitive processes involved in the formation of metaphors and analogies is important for understanding and improving the design process. Analogy and metaphor can be viewed as a mapping of knowledge from one situation to another enabled by a supporting system of relations or representations between situations [14–18]. This process of comparison fosters new inferences and promotes construing problems in new insightful ways. The potential for creative problem solving is most noticeable when the two domains being compared are very different on the surface [14].

Research has been carried out in the field of psychology to understand the cognitive processes people use for creating and understanding analogies and metaphors [19–21]. Figure 7 shows the basic process steps involved in reasoning. For illustration, this process will be explained as being applied to the design process even though

the same cognitive process occurs anytime a person reasons by metaphor and analogy. The process begins when a person learns a new piece of knowledge (encodes the source of inspiration for a future problem). At some future time, the person is faced with a new problem and must retrieve (remember) a suitable idea source to solve the new problem. Retrieving a useful analogy or metaphor is the most cognitively difficult step. Once a source is remembered, a mapping is created between the source and the new target situation. By developing these mappings we create new inferences.

Past empirical work on analogy

Design methods require a deep understanding of the processes people use and the areas where guidance or assistance could improve the process. This knowledge is gained through a combination of experimental work and naturalistic observation. Even though design-by-analogy is a well-recognized method, few experiments focus exclusively on analogy in design. Notable results from these experiments, however, include the work of Casakin and Goldschmidt [22], Ball *et al*. [25], Kolodner [23], and Kryssanov *et al*. [24]. Casakin and Goldschmidt found that visual analogies can improve design problem solving by both novice and expert architects [22]. Visual analogy had a greater impact for novices as compared to experts. Ball, Ormerod, and Morley investigated the spontaneous use of analogy with engineers [25]. They found experts use significantly more analogies than novices do. The type of analogies used by experts was significantly different from the type used by novices. Novices tended to use more case-driven analogies (analogies where a specific concrete example was used to develop a new solution) rather than schema-driven analogies (more general design solution derived from a number of examples). This difference can be explained because novices have more difficulty retrieving relevant information when needed and have more difficulty mapping concepts from different domains due to difficulty in identifying the pertinent information [23]. Experts more easily focus on the important features of a problem.

Prior research in analogical reasoning found the encoded representation of a source analogy (the analogous product) can ease retrieval if it is remembered such that the key relationships apply in both the source and target problem domains [26, 27]. The analogies and problems used in these experiments were not specific to any domain of expertise and used fantasy problems relying on strictly linguistic descriptions. The encoded representation result was replicated for realistic design problems [28–30]. It was further shown that the representation of the design problem had a significant impact on a designer's ability to retrieve an analogy and multiple representations of the design problem will ease analogical retrieval [30]. These studies show that representation plays a key role in memory retrieval and therefore also in design by analogy. By understanding the influence of representation, design by analogy and likely also metaphor use, can be enhanced through well-designed methods and tools.

Design is understood with metaphor

Because much of the discourse in design uses abstract concepts such as problems, solutions and ideas, we naturally use metaphors when we talk and reason about design and the design process itself. When a design team lists constraints to put boundaries on the design space, they are using metaphor. In this case, we reason that design takes place in a bounded space of possibilities.

Yet different metaphors provide us with a different understanding of design. For example, design researchers and authors have proposed alternative metaphors to design as search [31] including design as a process of selection [32], design as a process of exploration [33], design as bricolage [34] or design as a journey [35]. A designer who sees design as a process of selection is more likely to list options and then select between them, whereas a designer who views design as a process of exploration is more likely to generate and test a number of options, iterating towards a solution.

It is important that we, as design educators, are conscious of the perspectives on design that we pass to our students. Just as metaphors can serve as effective vehicles for communication among design teams, a disconnect in metaphors can serve to increase confusion between designers. Our flat and connected world [3] is characterized by increasing collaboration between designers from different countries and cultures. Accordingly we investigated whether designers from four different countries share a common understanding of creative design. Our data to this understanding are the different metaphors employed in popular design textbooks in use in these countries. As much of our basic reasoning is structured through metaphor, analyzing metaphors in common use provides insight into the way we understand and act upon these concepts [36].

We performed an analysis [13] of the conceptual design chapters of engineering and product development textbooks. These chapters contain a rich discussion of the concepts in engineering design and as such are a fruitful place to find example instances of metaphors. Studying conceptual design has the greatest potential to provide insight into creative design practices. In addition, design textbooks both educate and influence future designers' attitudes and practices. Prior research [13] has shown that different authors emphasize different dominant metaphors at the design process level, for example, Design Is Search or Design Is Decomposition. These metaphors in turn affect the metaphors and strategies in use for the design concepts of, for example, ideas, problems and solutions. For example, an author that stresses Design Is Decomposition is more likely to refer to problems as objects (that can be broken down,

Table 1. Number of unique qualifiers of design concepts and % overlap with those in US textbooks

	US	UK		Germany		Mexico	
	Total Qualifiers	Total Qualifiers	Overlap (%)	Total Qualifiers	Overlap (%)	Total Qualifiers	Overlap (%)
Ideas	79	9	100	24	96	14	86
Problems	29	24	54	5	80	3	100
Solutions	32	25	88	19	100	16	88
Total	140	58	76	48	96	33	88

solved in parts and reassembled). This metaphor stresses techniques like functional decomposition. Whereas an author that sees design as a process of search is more likely to see problems as locations to be avoided or gaps to be bridged in that space.

Cross-cultural comparison of design process metaphors

To determine whether US design students are taught similar perspectives on design as other countries, we broke down the analysis in [13] to six US design textbooks [37–42], one from Germany [43], and two from the UK [44, 45]. In addition, for the purposes of our analysis here, we analysed an additional Spanish design textbook in use in Mexico [46].

We followed the three phase process outlined in [13]:

1. Extracting instances of metaphors from design texts.
2. Categorizing the metaphor instances.
3. Identifying the coherent metaphors that make sense of the metaphor instances.

In total, over 430 individual metaphor instances were extracted from the textbooks. Each of the analyses was conducted on the English version of the textbooks with the exception of [46] which was evaluated by a bilingual researcher. The researcher extracted instances in Spanish and translated these for comparison with the remainder of the analysis.

To obtain a better feel for the analysis, here is an example of a metaphor instance:

''Brainstorming is meant first of all to *trigger off new* ideas, but it cannot be expected to *produce ready-made* solutions because problems are generally too *complex* and too *difficult* to be *solved* by *spontaneous* ideas alone.'' [43, p.78]

In the above extract, the design concepts of 'ideas', 'problems' and 'solutions' as referred to metaphorically, are underlined. The metaphorical qualifiers to each of these concepts are highlighted in italics. In the analysis, we listed all the qualifying statements for each design concept. In the example above, 'Ideas' can be *triggered off*, *new*, *spontaneous* and can *solve* problems; problems can be *complex*, and *difficult*; solutions can be *produced* and *ready-made*.

Two researchers compared the overlap of qualifiers for the design concepts 'ideas,' 'problems' and 'solutions,' between the US textbooks and non-US textbooks. Table 1 shows the results of this comparison.

Table 1 illustrates that the textbooks from Germany, Mexico and the UK share an 86.5 per cent overlap of qualifiers for 'ideas,' 'problems' and 'solutions' with those present in the US textbooks. What this means is that the three design concepts are conceptualized in largely the same ways across these different design cultures.

We believe this strong overlap in design metaphors reflects a largely consistent Western approach to design. We speculate that the global reach of information and the widespread use of English in academic design discourse play a key role in the apparent uniformity of current views on design. For example, while the Mexican design textbook was written in Spanish, it reflects many of the design ideas present in US textbooks that originate largely from within the US or Europe. While consistency may be beneficial to global collaborations, we believe it may also have a limiting effect on the development of new ways of thinking about design, especially within higher education.

To investigate further we intend to extend this study to East Asian design textbooks where we expect differences to be more pronounced. For example, other researchers have elaborated on the holistic cognition of East Asians versus the analytical cognition of Westerners [47]. In cultures where 'there was an absence not only of formal systems of logic, but indeed of a principle of contradiction', [47] this may be expected to have a profound impact on thinking about key design concepts such as conflicts, contradictions and trade-offs.

ANALOGIES AND METAPHORS IN THE DESIGN PROCESS

Metaphors as a tool for problem framing and solution generation

Other than affecting our high-level understanding of the design process, metaphors are a commonly touted design tool. Metaphors can be used at different stages of the process, both in the early stages as a tool for better understanding the design situation, descriptive metaphors, and also as a solution generation tool, prescriptive metaphors.

For example, seeing a cafeteria as an oasis not

only helps us understand the situation (as a descriptive metaphor) but may also lead to new solution directions as a prescriptive metaphor. The designer might consider how the feeling of an oasis could be better supported by the cafeteria, perhaps by providing places for rest or, better still, by closing it off from the outside world. In another example, a shower might be seen as a reset. It washes away the rest of the day and start renewed once they emerge. The metaphor, Shower Is A Reset, can be used to generate other solutions that could support people's feeling of starting anew even to the point of activating the shower with a button.

During concept generation, it is widely recognized that designers find it hard to ignore obvious constraints on their concepts before they have been fully developed. Various techniques such as brainstorming [48] encourage designers to defer judgment to allow ideas a chance to develop and be built upon before they are 'shot down.' Adams [49] proposes the concept of conceptual blocks and various methods to negotiate them. Several metaphors have also been proposed as a means of reducing the impact of obvious constraints on designers during concept generation. Altshuller [50] proposes the metaphor of a magic wand to encourage problem-solvers to free their imaginations and worry about the constraints afterwards. Stanford University's John Arnold proposed designing on the planet Arktur IV as a metaphor to help problem-solvers leave their earthly constraints behind. Each of these metaphors helps designers avoid early judgment by invoking the ideas of magic and other universes. Indeed, these metaphors are sometimes not far off reality as Arthur C. Clarke observed 'Any sufficiently advanced technology is indistinguishable from magic' [51].

Analogy use in concept generation

In contrast to metaphors, analogies tend to be used during the concept generation or ideation phase of design to find solutions to the design problem rather than to frame or assist in understanding it. Analogies to nature and previous designs are common. For example, a team with the design problem of creating a device to fold laundry may make direct analogies to other types of folding devices such as paper folding or metal folding. Likewise, more distant analogies may be made to dousing a sail, rolling a cigarette, or collapsing a structure. Analogies also support concept selection. When designers are evaluating a set of concepts, they will typically reference a design they have seen before in their evaluation. Designers thus use analogies to predict the performance of the design concept.

Design principles such as TRIZ principles [50] are also a type of analogy, which we define as a meta-analogy. Meta-analogies are high level abstractions that are formed from sets of analogies. TRIZ principles were developed from sets of innovative patents. Each individual patent is a single analogous solution for a design problem which can be solved with a given TRIZ principle. A closely related phenomenon is scheme-driven analogizing, which is the application of abstract experiential knowledge to a design problem [25].

The use of analogy and metaphor in the design process

In the following section we present results on the use of analogy and metaphor during the design process. Casakin [52] observed that architecture students found it easier to employ metaphors as a design tool in the early stages of design when framing and defining the situation. Here we extend Casakin's observations to compare the use of both analogy and metaphor at different stages of the design process. We were motivated by the hypothesis that metaphors are used more frequently during the early, problem framing, stages of the design process and analogies are used later in the concept generation phase. How does the actual use of metaphor and analogy play out in design?

METAPHOR AND ANALOGY USE BY NEW PRODUCT DEVELOPMENT TEAMS

We conducted interviews with 12 multidisciplinary new product development teams from a graduate course at the University of California, Berkeley. Teams were composed of business, engineering or information science and industrial design students. The teams worked on new product development projects largely following the process outlined in [37] from initial project idea, conducting user research, to presenting a user-tested prototype at a final tradeshow. Eleven interviews were performed in the final two weeks of the project and one was performed after the final tradeshow. Interviews were conducted with the full team present when possible, and the teams were asked to tell the story of their project from beginning to end explaining the key points as they saw them along the way. Although the group interview format has the potential to inhibit some group members from contributing, in practice it served to engender a rich discussion among the team as they each added to the story as they saw it. Interviews were then recorded, transcribed and coded for discussion of relevant product metaphors and use of analogy.

Though there was no formal teaching of metaphor use in design, eight out of 12 design teams highlighted a metaphor in the problem framing stage as an important factor in their project. For example, one team, developing a software product for social networking, searched for a suitable comparative business and used photo-sharing: "we saw it as organizing your collection of pictures, which is very tedious to do but once you have it nice to have. So that's what we thought we were trying to do with networking . . . it's kind of

annoying to do networking all the time but it's nice to have a social network in the end''. Extending the photo-sharing comparison the team explained ''we were the Flickr of social networking—And it just helped us frame the whole process''.

A team investigating electronic textbook delivery developed a restaurant metaphor to help understand their design situation and the student experience. ''Educational content was like food in a meal. And so the publishers are like chefs in the kitchen preparing the content and because there's an agency problem the professors order for you and so then you get served—so there are three aspects to the student experience—it's getting served the content, eating and digesting the content and then enjoying the content as in discussing it after the fact. It was actually quite relevant because we had to talk about how do you serve things up versus how do you facilitate some of the ability to access them and digest them on their own and then share those thoughts.''

Another team began with the goal of developing software that would help designers see manufacturing errors in CAD models before they went to manufacture. As one member explained: ''If the user is making a model using CAD software the software will do the error detection in real time and give the feedback in real time. Something like a spelling checker in Microsoft Word. It does it in the background . . .''

One team, looking for opportunities to integrate computing into the kitchen developed a platform-based solution after realizing from their research that the kitchen was an organic, messy space: ''I think sort of what our platform has become is tailored for picking this section of the problem. And then you know the rest can grow out from there because it's an organic space. It's a messy space. It's not supposed to be very regimented, it's the kitchen. It allows for some freedom there.'' The insight of the organic nature of the kitchen directed the team towards the flexible platform solution.

Further examples include a team that explored developing a NASCAR style fast food drive-through experience, and a team developing a device to remove blood clots that viewed the situation as akin to plumbing—they were creating pipes.

ANALOGY AND METAPHOR USE BY DESIGNERS DURING CONCEPT GENERATION

For comparison to the metaphor use data, we coded the use of metaphor and analogy from a prior study where design teams were asked to use a particular group idea generation technique and then spend forty minutes generating solutions to a design problem [53]. Again 12 teams were analysed. All the group idea generation techniques evaluated for the study required teams to use only written communication. This study was a 3×2 factorial design. The first factor controlled the representation teams used for communication (words only, sketches only, or a combination). The second factor controlled how team members exchanged ideas, either all the ideas were posted on the wall or each team member had a subset of the ideas and they rotationally exchanged them. Teams consisted of five senior mechanical engineers. The experiment asked the teams to design a device to shell peanuts.

The analogy coding was based on clear references to other designs, such as 'analogy to potato peeler' or 'this is like a grill'. This approach underestimates the actual number of analogies used by the design teams. Designers frequently use analogies without making explicit references and frequently without realizing the source of their idea [54, 29]. In addition, the coding cannot explicitly evaluate if the analogy was being used as an explanation tool or if the idea had been developed based on the analogy. A common use of analogy is to explain an idea rather than as an original source of inspiration [54]. However, from observations of the coding process, it appeared clear that many analogies were being used for idea generation, as opposed to just explanation.

Comparison of metaphor and analogy use

Our analysis shows that student design teams employ both analogies and metaphors in the design process (Fig. 8). Table 2 shows that over 65 per cent of the design teams, in our studies, used metaphors to frame their problems and about half of the design teams took advantage of analogies to

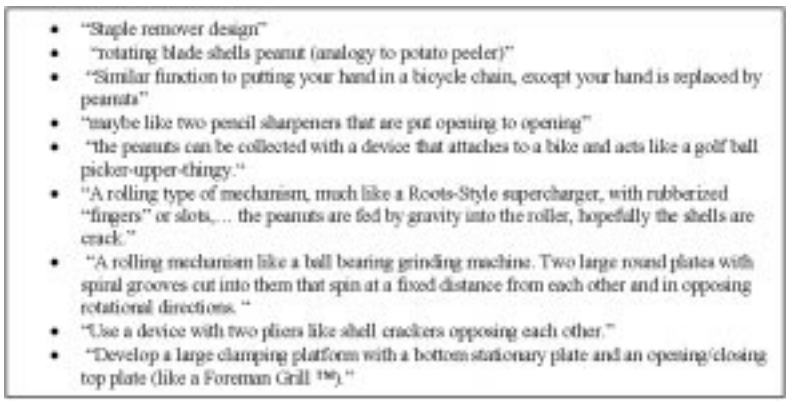
- "Staple remover design"
- "rotating blade shells peanut (analogy to potato peeler)"
- "Similar function to putting your hand in a bicycle chain, except your hand is replaced by peanuts"
- "maybe like two pencil sharpeners that are put opening to opening"
- "the peanuts can be collected with a device that attaches to a bike and acts like a golf ball picker-upper-thingy."
- "A rolling type of mechanism, much like a Roots-Style supercharger, with rubberized "fingers" or slots,... the peanuts are fed by gravity into the roller, hopefully the shells are crack."
- "A rolling mechanism like a ball bearing grinding machine. Two large round plates with spiral grooves cut into them that spin at a fixed distance from each other and in opposing rotational directions."
- "Use a device with two pliers like shell crackers opposing each other."
- "Develop a large clamping platform with a bottom stationary plate and an opening/closing top plate (like a Foreman Grill TM)."

Fig. 8. Example of analogies teams used to assist in designing a device to shell peanuts.

Table 2. Analysis of analogy and metaphor use in a concept generation activity

	Problem Definition Phase (Design Process Interviews, n=12)	Concept Generation Phase (Concept Generation Experiment, n=12)
% of teams using analogies	8%	50%
% of teams using metaphors	67%	8%

generate solutions. Students who took part in the concept generation experiment were previously exposed to using analogies for idea generation in their engineering design methods class. While analogy use to generate solutions appeared spontaneous, almost no metaphors were mentioned in concept generation. Students who had been exposed to the technique of design-by-analogy spontaneously used it when asked to generate design solutions. This result replicates prior findings [28, 30], but does so within the real-world knowledge domain of engineering.

As Table 2 shows, metaphors were most frequently used to frame the design situation whereas analogies were most common for generating solutions to the design problems. Although these data are not sufficient to prove this trend, the result is compelling and warrants further investigation. Our data support Casakin's results that students had an easier time employing metaphors to assist in framing their problem as opposed to using it to generate solutions [52]. The data from the new product development interviews illustrated use of metaphor in the early problem framing stages of the design process. For example, the 'Flickr of social networking,' the education restaurant metaphor, and the manufacturing spell-checker metaphor allowed the teams to see their design situation in a different way. These results are in contrast to the results of the analogy study that showed how analogy contributed directly to the development of new solution concepts rather than providing an understanding of the design situation.

The prevalence of metaphor in the early stages of the design process may stem from the teams' search to understand a complex human design situation. A metaphor helps bring structure to the design situation and acts as a meaningful communication tool to the rest of the team. The metaphor helps the design teams figure out a story that makes their design project make sense. In contrast, the concept generation phase is often concerned with more technical aspects of design problem solving where the emphasis is on finding a technical solution that will work and is innovative rather than a story to help make sense of the situation.

EXTENDED APPLICATIONS AND IMPLICATIONS FOR EDUCATION

The way in which engineers conceptualize individual design problems and the overall design process affects the end results. Metaphors used to describe and understand the design process stress certain aspects such as 'design is search' while concealing others, such as 'design is a journey'. This structure can lead to too much or too little emphasis on particular steps in the process. Metaphors and analogies employed within the design process on a particular product also highlight particular elements of the design or of the design space.

The analysis of metaphors found in British, American, Mexican and German engineering design textbooks shows that the design process is conceptualized in largely similar ways across these cultures. This result has an important implication as engineers work in a global environment. One key global challenge is that engineers define and solve problems differently [55]. Our analysis shows that engineers across these countries will likely conceptualize the overall design process in similar ways and thus this is less likely to be a point of conflict.

The data in this paper on analogy and metaphor along with the prior empirical work show the importance of both analogy and metaphor in the design process. Professionals frequently use both in the design process [56, 22, 57]. Students need to be taught how to effectively employ analogies and metaphors symbiotically in the design process. Formal design methods do exist for using both analogy and metaphor in design [58–62]. Current design-by-analogy methods give little guidance on how to find analogous products or require the creation of a repository of prior solutions [60, 61]. Design methods for metaphors also leave the finding of a suitable metaphor to the team's experience or to analysis of user research. Our results suggest that tools and methods to assist in the search process for suitable analogies and metaphors would benefit designers.

Design method for metaphor and analogy

Outlined in Fig. 9 is a basic method based on prior empirical research for seeking analogies to assist in solving a design problem. Our prior research shows that by creating multiple representations of a design problem, designers are more likely to think of a larger set of analogies that can be used to solve it [30]. The methodology shown in Fig. 9 employs this result and symbiotically uses metaphors and analogies through re-representation. The process begins with an initial problem statement. The initial problem statement may be created with any approach, for example customer needs gathering, see [41]. Once a design team has

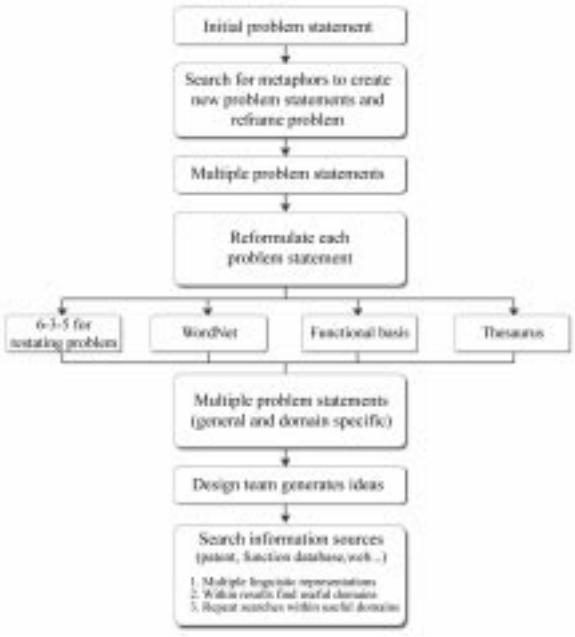

Fig. 9. Overview of a teachable design method employing metaphor and analogy.

an initial problem statement they then search for metaphors to reframe the problem in other ways. For example if the problem statement is to 'Design a device to fold laundry for people with severe disabilities' a metaphor could be thinking of Laundry as a Game. The design problem would include making the process enjoyable. The use of metaphors then leads to multiple problem statements.

Each of the problem statements is then rerepresented linguistically, Fig. 10. First a design team generates ideas for other ways of stating or thinking about the design problem. Teams then find synonyms for the key words in their problem statements using a thesaurus or WordNet [63]. WordNet has the advantage of also connecting to more general or domain specific ways of stating the same thing, known as hypernyms and troponyms, for example, suggesting vehicle for train, or

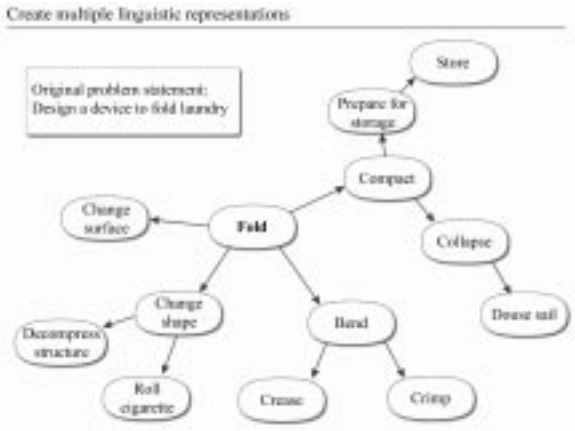

Fig. 10. An example of creating multiple linguistic representations of a problem statement. Each representation will trigger different analogies.

amble for walk. If a design team contains members who are multilingual, then the design problem may also be represented in other languages. This process results in numerous linguistic representations of the design problem. The design team then uses these representations to generate analogies and solutions to the design problem. The variety of representations prompts a wide variety of ideas through analogy and analogical domains.

Finally, the various linguistic representations are used for key word searches in various information sources such as patent databases, product repositories or a function database [64].

CONCLUSIONS AND FUTURE WORK

This paper assists future design engineers by explicating the roles of analogy and metaphor in creative design. We clarify the distinction between metaphor and analogy in the design process. Results from our interviews and experimental data show that student designers use both analogy and metaphor within the design process. More significantly, the results suggest that metaphor use is primarily employed in the early problem framing stages of design to enhance understanding of a design situation. Conversely, analogy is mostly used in the concept generation phase of design to map the causal structure between a source idea in one domain to the target design problem being solved.

We also discuss the influence of metaphor on our understanding of design itself. Analysis of the metaphors used in popular design textbooks from Germany, the UK and Mexico showed an 85 per cent overlap in metaphor usage with those in US textbooks. This result suggests that cross-cultural differences in the understanding of design between design teams are likely to be small.

The results of these findings lead to a general methodology to more effectively use metaphors and analogies in design or innovation processes. This methodology may be adapted for use within particular engineering classrooms, educational design processes, or industrial development processes.

Further studies will be performed on the use of metaphor and analogy in different stages of the design process to determine the robustness of the results presented here. The design by analogy method presented will be tested and its effectiveness measured for creative design.

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