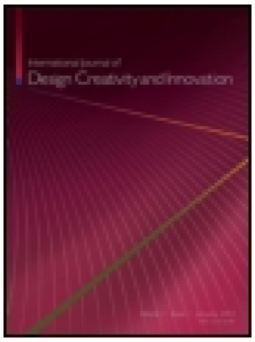

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Incremental to radical ideas: paradigm-relatedness metrics for investigating ideation creativity and diversity

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ABSTRACT
Creativity and diversity are key components of success in idea generation, but each includes many dimensions. Paradigm-relatedness is an indicator of the style of creativity and diversity that has been overlooked often in assessing ideation. The goals for this study were to synthesize the literature on paradigm-relatedness, and develop and test alternative approaches for operationalizing paradigm-relatedness in ideation. The synthesis of the literature focused on reviewing both paradigm-relatedness theoretical frameworks and methodological approaches. Then, two alternative paradigm-relatedness metric approaches—*category-based* and *component-based*—were developed. Finally, ideation data was collected and coded to evaluate the reliability, ease of use, and potential applications of each approach. The *category-based* approach was a more reliable and faster way to code paradigm-relatedness, and so it may be more suited for research or evaluation at scale. In contrast, the *component-based* approach provided more explicit information on all aspects of paradigm-relatedness, but was more challenging to code reliably and more time-consuming. The *component-based* approach may be more suited to guiding smaller teams or individual designers in achieving paradigm-relatedness creativity and diversity. Neither approach was found to be universally ideal, and so consideration of the trade-offs is important in deciding which is most appropriate in a given situation.

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Idea generation; creativity evaluation; research methodology

1. Introduction and Background

Both solution creativity and solution set diversity are key goals of ideation (Dow et al., 2010; Liu, Chakrabarti, & Bligh, 2003; Reinig, Briggs, & Nunamaker, 2007; Shah, Vargas Hernandez, & Smith, 2003). Various measures of idea creativity exist (Dean, Hender, Rodgers, & Santanen, 2006), including holistic judgments made by multiple members of a field (Amabile, 1982; Christiaans, 2002), or combinations of various more objectively-rated subcomponents (Dean et al., 2006; Gruys, Munshi, & Dewett, 2011). However, in most cases, creativity metrics do not make a distinction between different types of creativity. Similarly, although design researchers have developed systematic ways to characterize the diversity of ideas generated by an individual or team (e.g., Nelson, Wilson, Rosen, & Yen, 2009; Shah

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et al., 2003; Verhaegen, Vandevenne, Peeters, & Duflou, 2013), they do not characterize different types of diversity. The distinction between incremental and radical ideas is one lens to consider different types of creativity and diversity (Norman & Verganti, 2014; Sternberg, 1999, 2005). Being able to identify different types of creativity and diversity is potentially valuable in guiding a designer's processes for generating additional creative ideas that more fully explore the design space (Grace & Maher, 2015; Sarkar & Chakrabarti, 2014).

Successful ideas may be found anywhere along a continuum from incremental to radical (Abernathy & Utterback, 1978). Sometimes the best ideas are incremental improvements that lead to evolutionary changes, resulting from refining existing solutions to perform better in their primary context or extending them to similar contexts (Norman & Verganti, 2014; Sternberg, 1999, 2005). There are also times when the best ideas are radically new ways of solving the problem that lead to revolutionary changes, resulting from viewing the problem from different perspectives or connecting seemingly unrelated ideas within the problem context. Although it may be common to assume that more radical ideas are associated with higher levels of creativity (Puccio & Chimento, 2001), both types of ideas can be considered creative. That is, there are uncreative radical ideas and highly creative incremental ideas (Puccio, Treffinger, & Talbot, 1995; Talbot, 1997). Additionally, the value and necessity of ideas across the incremental-to-radical spectrum has been established with theoretical arguments and empirical studies (Ettlie, Bridges, & O'Keefe, 1984; Garcia & Calantone, 2002; Kirton, 2011; Norman & Verganti, 2014; Valle & Vázquez-Bustelo, 2009). Designers put themselves in the best position to succeed by pursuing both incremental and radical ideas.

Measuring creativity and diversity with this incremental-to-radical perspective could benefit researchers, designers (both students and practitioners), and design educators by broadening our understanding of what counts as successful ideation and, in turn, the conditions for obtaining that success. For example, a designer's exploration of the solution space may be limited by both population biases that tend to associate creativity with radical ideas (Puccio & Chimento, 2001) and personal preferences that make it more likely an individual will assess an idea as being creative when it aligns with their preferences (Puccio et al., 1995; Talbot, 1997). To counteract these tendencies, one option might be to intentionally 'seed' example ideas of one type or another. Examples have been shown to lead to the generation of more ideas of that same type (Garfield, Taylor, Dennis, & Satzinger, 2001; Satzinger, Garfield, & Nagasundaram, 1999). Another option might be to select an ideation technique (McFadzean, 1998; Shah, Kulkarni, & Vargas Hernandez, 2000) designed specifically to lead to generating ideas of a certain type. However, the evidence so far has been inconsistent as to whether particular ideation techniques reliably result in ideas of the type they were designed to encourage (Garfield et al., 2001; Gryskiewicz, 1980; Hender, Dean, Rodgers, & Nunamaker, 2002; Nagasundaram, 1995; Nagasundaram & Bostrom, 1995). More accessible metrics may help enable further research to better clarify the conditions that are effective at encouraging designers to generate ideas in parts of the solution space that may otherwise go unexplored.

To be most useful, the metrics that assess where ideas lie along the incremental-to-radical continuum should be both grounded in theory and usable in practice in a wide range of design contexts. *Paradigm-relatedness* has been proposed as a measure of different types of creativity, rather than an idea's creative level (Nagasundaram & Bostrom, 1994). Paradigm-relatedness aligns strongly with the incremental-to-radical continuum of design ideas as 'paradigm' refers to the prevailing ways of perceiving and acting in a given situation or problem, and 'relatedness' refers to the extent to which an idea operates within or challenges that paradigm (Garfield et al., 2001; Satzinger et al., 1999). Modest changes that operate largely within the status quo are termed *paradigm-preserving* and more substantial shifts are termed *paradigm-modifying*. Thus, paradigm-relatedness has the potential to serve as a useful framework for characterizing, differentiating, and evaluating this incremental-to-radical aspect of the creativity and diversity of ideas.

In the present study, we conducted a literature review synthesizing both the theoretical and empirical underpinnings of paradigm-relatedness. Building on this synthesis, we developed two alternative metric approaches to evaluate the paradigm-relatedness of design concepts. We then conducted some preliminary testing of these alternative paradigm-relatedness metrics using a data-set of ideas generated by engineering students. We compared the reliability and ease of use when applying the metrics, and the ability of the metrics to differentiate key qualities of paradigm-relatedness. Finally, we evaluated the results in terms of the usefulness of the different paradigm-relatedness metrics for various design-focused pursuits, including in the workplace, the classroom, and research. The following questions guided our work:

(1) How can the prior paradigm-relatedness research be synthesized to highlight the critical aspects of paradigm-relatedness as one aspect of creativity and diversity?
(2) What might the development of new paradigm-relatedness metric approaches look like that are consistent with prior paradigm-relatedness research while being transferrable to a wider variety of problem contexts?
(3) What are the benefits and drawbacks of the new paradigm-relatedness metric approaches and in what situations are each best suited?

Answers to these questions could support the development of a common, accessible, and theoretically grounded basis to guide future research utilizing paradigm-relatedness. Other studies have investigated various measures for creativity (Grace, Maher, Fisher, & Brady, 2015; O'Quin & Besemer, 1989) and diversity (Linsey et al., 2011; Shah et al., 2003), however even metrics that consider various subcomponents of these qualities do not focus on the details of defining paradigm-relatedness. Additionally, while in some cases paradigm-relatedness has been the focus of metric development (Dean et al., 2006; Nagasundaram & Bostrom, 1994), there is a gap in understanding tradeoffs in its assessment. This paper adds to the literature by more explicitly positioning paradigm-relatedness as a measure of different styles of creativity and diversity, and better specifying theoretical aspects of paradigm-relatedness and their relation to the practical use of the metric in specific design contexts.

2. Synthesis of prior literature on paradigm-relatedness

To address our first question, we (1) describe the relationship between creativity and paradigm-relatedness in evaluating design ideas, (2) review different paradigm-relatedness theoretical frameworks to define the conceptual space that is covered by the paradigm-relatedness construct, and (3) discuss different ways that paradigm-relatedness has been operationalized in empirical studies.

2.1. Paradigm-Relatedness as a Dimension for Characterizing Creative Style

While creativity of a person, process, or environment can be investigated (Rhodes, 1961), our focus is on the creativity of an idea or product (Plucker, Beghetto, & Dow, 2004). Although creativity is a critical indicator of ideation effectiveness, creativity is complex and not simple to characterize on just one dimension. Many scholars agree that in order for an idea to be considered creative it must be both *useful* and *novel* (Amabile, 1996; Besemer & O'Quin, 1987; Dean et al., 2006; Kudrowitz & Wallace, 2013; Plucker et al., 2004; Sarkar & Chakrabarti, 2011, 2015). Dean et al. (2006) developed a hierarchical multi-dimensional model of creativity with *usefulness* and *novelty* as the two primary dimensions, but then each primary dimension was defined by multiple sub-dimensions. *Usefulness*—sometimes referred to as *value* or *quality*—involved considering three sub-dimensions that included an idea's *workability*, *relevance*, and *specificity*. *Novelty* included two sub-dimensions—an idea's *originality* and *transformational* power (Dean et al., 2006). While *originality* refers to the extent to which an idea is rare and distinct from existing designs, *transformational* refers to the extent to which an idea involves conceptualizing the problem context in an atypical way (Besemer & Treffinger, 1981; Boden, 2004; Grace & Maher, 2015). Nagasundaram and Bostrom (1994) proposed that this second transformational aspect of novelty corresponds to what they termed *paradigm-relatedness*. Other models of creativity do exist (Brown, 2014; Oman, Tumer, Wood, & Seepersad, 2012), including those that consider surprise as either a subcomponent of novelty (Besemer, 2000, 2006) or as a distinct aspect of creativity (Grace et al., 2015; Macedo & Cardoso, 2001; Maher, Brady, & Fisher, 2013). However, even in the models incorporating surprise, an idea's transformational aspect can be considered a distinct component of creativity (Grace & Maher, 2015).

Dean et al. (2006) found empirical support for their multi-dimensional model, as paradigm-relatedness had a high positive correlation with originality, moderate negative correlations with workability, and weaker positive correlations with specificity. Further, in a factor analysis, both novelty sub-dimensions (originality and paradigm-relatedness) and workability loaded strongly onto the same factor, but while the novelty dimensions loaded positively, workability loaded negatively. Dean et al.'s findings suggested there may be a trade-off such that ideas that are more paradigm-modifying tend to be less immediately workable, but that ideas across the spectrum of paradigm-relatedness can be more or less specified. In the end, Dean et al. found that paradigm-relatedness was a distinct aspect of creativity.

In this multi-dimensional view, almost all of the creativity sub-dimensions are an assessment of an idea's *creative level*—the *extent* to which an idea is creative (Goldsmith, 1987; Kirton, 1976, 2011; Nagasundaram & Bostrom, 1994). The one exception is *paradigm-relatedness*, which aligns more explicitly with an idea's *creative style*—the *way* in which the idea is creative (Isaksen & Puccio, 1988). That is, whether an idea is more paradigm-preserving or more paradigm-modifying is an indicator of that idea's style of creativity, while neither type is inherently more or less creative than the other. Creative level and creative style have been shown to be independent, which suggests that these two aspects of ideas can be assessed separately (Isaksen, Babij, & Lauer, 2003; Kirton, 2011; Mudd, 1996).

No single metric on its own can fully answer the question of whether ideation has been successful. Indeed, the review of the research on creativity metrics suggests that paradigm-relatedness—although commonly overlooked—should be considered alongside other metrics like usefulness, originality, and surprise (Dean et al., 2006; Grace & Maher, 2015; Kudrowitz & Wallace, 2013). Similar to the argument to consider surprise separate from novelty (Barto, Mirolli, & Baldassarre, 2013; Grace et al., 2015; Macedo & Cardoso, 2002; Macedo, Cardoso, Reisenzein, Lorini, & Castelfranchi, 2009; Palm, 2012; Schmidhuber, 2009; Schwartenbeck, FitzGerald, Dolan, & Friston, 2013), because paradigm-relatedness aligns distinctly with an idea's creative style, it may also highlight a distinct dimension of diversity. Hence, paradigm-relatedness may have value in guiding designers to explore wider ranges of possible solutions that consider the problem from multiple perspectives or to sharpen a focus on one perspective and deepen the search within that perspective. However, to make use of paradigm-relatedness alongside other creativity metrics, a common definition of the underlying construct is necessary.

2.2. Paradigm-relatedness theoretical frameworks

Three theoretical frameworks have formed the basis for defining paradigm-relatedness (Dean et al., 2006; Gryskiewicz, 1980; Nagasundaram & Bostrom, 1994). Each of these theoretical frameworks made explicit the different categories of paradigm-relatedness and the distinctions and boundaries between those categories. We compared the three theoretical frameworks—summarized in Table 1—and review each in turn.

Gryskiewicz (1980) proposed a metric called 'Categories of Responses' that served as a framework to classify ideas with respect to staying within the explicit problem definition (*direct*) versus going beyond it (*tangential*; Table 1 second column). He translated these general categories into terms specific to the *Tea Bag* problem ('What else could be packed into a tea bag other than tea?'). For example, a *direct* idea was one that did not involve any modification to the bag itself, simply filling it with something besides tea, such as sugar. A *tangential* idea made use of the tea bag materials in a way that the bag-like function was no longer a constraint, such as for curtains (Gryskiewicz, 1980). Gryskiewicz's categories were explicitly aligned with creative style (Kirton, 1976) as they were developed to span the spectrum upon which different individuals understood and utilized *constraints* and *assumptions* in the given problem. A more incremental response involved operating within the given confines of how a problem was initially presented. A more radical response involved treating the constraints from the problem

Table 1. Paradigm-relatedness frameworks.

Category	Constraints & assumptions (Gryskiewicz, 1980)	Elements & relationships (Nagasundaram & Bostrom, 1994)	Elements & relationships + focus (Dean et al., 2006)
1	*Direct* Does not modify the original product and stays well within constraints defined by the problem as given	*Refine* Introduces neither new elements nor alters relationships normally associated with the problem situation	*Paradigm preserving* Typical or usual ways of solving the problem
2	*Supplementary* Involves a new use for the original product, but keeps original product largely intact	*Extend* Introduces elements that are not normally associated with the problem situation	*Slightly Paradigm Stretching* Introduces new elements but still focuses on the problem as given
3	*Modify* Involves a structural change (size, shape, color and materials used) or modification to the original product, but similar function of original product is maintained	*Redesign* Alters the relationships between elements that are normally associated with the problem situation	*Paradigm Stretching* Changes the relationships of the user in the given context (includes research)
4	*Tangential* Involves different functions for materials used in the construction of the original product, and the original product function is no longer apparent	*Transform* Both introduces new elements and alters the relationships between those elements in ways not normally associated with the problem situation	*Paradigm Breaking* Introduces new elements and changes relationships of the user in the given context. Also includes ideas that focus on a larger problem or that include more radical ideas

description as assumptions that could be reconsidered. Even while the categories represented different 'levels' or extents of treating constraints as assumptions, Gryskiewicz claimed that no category was a higher level of creativity than the others. Consistent with notions of creative style explained earlier, each category simply reflected a different way to approach the problem.

Nagasundaram and Bostrom (1994) first introduced the term *paradigm-relatedness*, and made explicit that paradigm-relatedness was a measure of an idea's creative style, 'independent of and orthogonal to the creativity level' (Nagasundaram & Bostrom, 1994, p. 89). Nagasundaram and Bostrom proposed their own framework of four categories (Table 1 column three). They used the term *paradigm-preserving* (PP) to describe ideas in their first category—*refinement*—that neither introduce new elements nor alter the relationships between elements commonly associated with a problem context. They defined three other categories, all of which they labeled as *paradigm-modifying* (PM), although *transformational* ideas were considered to represent a greater extent of paradigm-modification, while *extended* or *redesigned* ideas were said to represent more moderate paradigm-modification (Nagasundaram & Bostrom, 1994). Instead of Gryskiewicz's attention to *constraints* and *assumptions* in the problem definition, Nagasundaram and Bostrom focused on *elements* and *relationships* within the problem context, which suggests that these may be two distinct approaches to understanding paradigm-relatedness.

Finally, Dean et al.'s (2006) framework was also based on four categories of ideas that varied along the paradigm-relatedness spectrum. Dean et al. now used the 'paradigm' term directly in the category labels (Table 1 final column). Dean et al. used Nagasundaram and Bostrom's language of elements and relationships in defining the three more paradigm-modifying categories. However, they also added the language of *focus* in the highest paradigm-modifying category, which refers to whether an idea addresses a higher goal than the one explicitly stated in the problem. One problem Dean et al. used was the *Restaurant* problem ('What can the restaurant do to retain its customers?'). Translating their general framework into problems-specific terms, a *paradigm preserving* idea maintained the original focus of the problem by continuing to serve food to students, such as proposing to hand out flyers to attract more students. A *paradigm breaking* idea refocused on the larger problem of the restaurant needing to stay in business, and so an idea in that category might involve pivoting to sell a non-food-related product (Dean et al., 2006).

The frameworks represent different ways to recognize the extent to which an idea works within the paradigm of a given problem or extends beyond it. Implicit constraints and assumptions (Gryskiewicz, 1980), common elements and relationships (Nagasundaram & Bostrom, 1994), and stated focus or goals (Dean et al., 2006) are each ways of defining the paradigm of a problem, but each foreground different components. Considering their use in empirical ideation studies can clarify how the variation in emphasis and language captures different components of paradigm-relatedness.

2.3. Operationalizing paradigm-relatedness in empirical studies

Paradigm-relatedness has not been considered explicitly in much of the current empirical research on ideation in design and engineering. Although arguably a critical sub-dimension of novelty, Dean et al. (2006) found that 30 of the 90 studies they reviewed measured originality compared with just six studies that measured paradigm-relatedness (Dean et al., 2006; Garfield et al., 2001; Gryskiewicz, 1980; Hender et al., 2002; Nagasundaram, 1995; Satzinger et al., 1999). In addition to being rare, paradigm-relatedness research has been limited to studies of ideation with undergraduate business students and has utilized just four problem contexts—the *Tea Bag* and *Restaurant* problems described above, plus the *Parking* ('What can be done to improve the parking situation on campus?') and *Tourists* ('How can the city of Tucson attract more tourists?') problems. The limited contexts may facilitate comparisons across studies, but may not be representative of the variety of design disciplines that value creativity. One reason that paradigm-relatedness may not be commonly used is that it is not simple to measure in new problem contexts. Paradigm-relatedness may require a context-specific coding scheme to reliably assess ideas (Dean et al., 2006), and so a lack of a well-defined process for translating more general paradigm-relatedness frameworks to specific contexts may be limiting its use.

In reviewing the empirical studies, we found the operationalization of paradigm-relatedness was not always clearly aligned with the theoretical frameworks on which the studies were based. For one, the theoretical frameworks (Table 1) were based on distinct paradigm-relatedness components which theoretically could be assessed separately, but none of the studies coded paradigm-relatedness this way. For example, in Nagasundaram and Bostrom's (1994) theoretical framework, elements and relationships were explicitly theorized as two independent and orthogonal components, but were not coded independently in their work (Nagasundaram, 1995; Nagasundaram & Bostrom, 1995; Satzinger et al., 1999). Instead, based on the work of Gryskiewicz (1980), the predominant method was to use a category-based coding scheme (Dean et al., 2006; Garfield et al., 2001; Gryskiewicz, 1980; Nagasundaram, 1995; Satzinger et al., 1999). The one exception is Hender et al. (2002), who chose to use a seven-point Likert scale but did not specify what each level represented, so it is not possible to determine how those levels map onto the theoretical frameworks.

Category-based coding schemes involved identifying four or five broad categories of context-specific solutions to a particular problem, and then coding each idea into one of the categories. Although the context-specific categories do align roughly with each theoretical framework's four general categories, none of the authors described explicit processes for determining the context-specific categories. One method may be to group related ideas from a set of predicted or observed ideas, and then align those groups with a theoretical framework's general categories (Dean et al., 2006; Gryskiewicz, 1980; Nagasundaram & Bostrom, 1994). A potential issue with that approach is that while most problem contexts utilized four context-specific categories, the *Parking* problem had five, which means there needed to be an additional process for reducing those five so they map onto the four general categories in the theoretical framework.

Another issue to consider is how the categories map onto different extents of paradigm-relatedness. In all cases of researchers who have used these category-based coding schemes, the categories were ordered from paradigm-preserving to paradigm-modifying. However, three of the six studies (Garfield et al., 2001; Nagasundaram, 1995; Satzinger et al., 1999) ultimately reduced the categories to just two final levels for analysis purposes: (1) paradigm-preserving or (2) paradigm-modifying. For example, in the *Tea Bag* problem, Nagasundaram assigned only the first category to be paradigm-preserving (Nagasundaram, 1995), while the other three were all considered paradigm-modifying. Gryskiewicz (1980) and Dean et al. (2006) left their category-based coding as a four-level scheme. This choice aligned more clearly with their respective theoretical frameworks, as the four general categories indicated the different extent of paradigm-relatedness, and also supported more differentiated analyses. Thus, collapsing the categories has a potential trade-off in that having just two levels may be easier to manipulate or contrast in research designs. However, doing so obscures the ability to differentiate the full spectrum of paradigm-relatedness, potentially resulting in less sensitivity to the diversity represented in different sets of ideas or more subtle shifts that individuals may make in their ideation from one situation to another (Silk et al., 2016).

In sum, paradigm-relatedness has been operationalized in a few, limited problem contexts. The category-based coding seems to be a productive way to operationalize paradigm-relatedness in a context-specific way, and is reasonably aligned with the theoretical frameworks, although not always in a one-to-one mapping. However, the categories make it difficult to examine the different paradigm-relatedness components separately and are not always used in ways that differentiate the full spectrum of paradigm-relatedness. As a result, clarifying the distinctions between different levels of paradigm-relatedness as well as considering ways to operationalize paradigm-relatedness components separately may make the underlying theoretical distinctions of paradigm-relatedness more explicit. These clarifications may also result in a clearer process of translating the general theoretical frameworks to context-specific measures, making it more straightforward to utilize paradigm-relatedness in a broader set of contexts.

3. Development of alternative paradigm-relatedness metrics

In this section, we describe our development of a revised category-based metric and an alternative component-based metric for paradigm-relatedness. The category-based metric integrates existing paradigm-relatedness theoretical frameworks, while the component-based metric expands on existing metrics by differentiating multiple sub-dimensions of paradigm-relatedness. These sub-dimensions have been theorized to be underlying paradigm-relatedness components, but have not been coded formally before.

3.1. A revised category-based paradigm-relatedness metric

To develop our general category-based paradigm-relatedness metric, we built off the prior frameworks (Table 1). The category-based metric is presented in Table 2. We kept the same labels for the four categories as Dean et al. (2006), since those labels make explicit the continuum along the paradigm-relatedness spectrum. Although the Dean et al. framework incorporated aspects of the two prior frameworks (Gryskiewicz, 1980; Nagasundaram & Bostrom, 1994), we made some modifications that more explicitly took into account aspects of all three. In particular, we chose to use the language of constraints and assumptions in our third category, as discussed by Gryskiewicz (1980) but not formally incorporated into his framework beyond his first category. We also chose to combine elements and relationships into the second category, because in Nagasundaram and Bostrom's (1994) framework, introducing new elements or relationships represent a similar level of paradigm-modification. The resulting category-based paradigm-relatedness metric captured the critical theoretical aspects of all three prior paradigm-relatedness frameworks.

3.2. An alternative component-based paradigm-relatedness metric

Our general component-based paradigm-relatedness metric was based on the range of ways researchers have theorized underlying components of paradigm-relatedness. The component-based metric is presented in Table 3. This alternative framework was intended to make explicit each component of paradigm-relatedness in a way that could apply across problem contexts. The different components included *elements*, *relationships* (Dean et al., 2006; Nagasundaram & Bostrom, 1994), *constraints* and *assumptions* (Gryskiewicz, 1980), and *focus* (Dean et al., 2006; Garfield et al., 2001; Satzinger et al., 1999). *Elements* and *relationships* were separated as distinct components because both Nagasundaram and Bostrom (1994) and Dean et al. (2006) differentiate them and assign each to their own category in their frameworks. The component each had two levels, *paradigm-preserving* (1) or *paradigm-modifying* (2), because our synthesis of the literature did not differentiate finer-grained distinctions between additional levels within each component.

Each of the four components can be considered a measure of paradigm-relatedness on its own, as they each have been the basis for defining categories in at least one of the existing theoretical frameworks. However, it may be that each component is just one aspect of an overall paradigm-relatedness construct that combines and integrates them together. Differentiating the four components allows for testing their independence and exploring potential underlying factors that might connect them. However, it is then also important to articulate an additional overall paradigm-relatedness component. Because paradigm-relatedness is a particular type of creativity that may be counterintuitive to most people, we determined that it would be appropriate to have the raters base their decision on an overall sense of the idea's paradigm-relatedness, while still providing the different components of paradigm-relatedness as additional information to consider in their overall judgment. Dean et al. (2006) identified a number of studies that have used this approach when evaluating the creativity of ideas at a more holistic level (e.g., Kramer, Kuo, & Dailey, 1997). Having separate individual components along with the overall paradigm-relatedness component would enable future work to investigate the potential relationships between the components. For example, is one of the components more prominent

Table 2. Revised general paradigm-relatedness category-based metric.

Category	General category description	Connections to prior frameworks
1	*Paradigm-preserving* Solution resembles an already existing, common design, stays well within constraints defined by the problem as given and typical assumptions, and does not introduce new elements nor alter relationships normally associated with the problem situation	Aligns well with all three prior frameworks (Dean et al., 2006; Gryskiewicz, 1980; Nagasundaram & Bostrom, 1994) while integrating language from each of them (constraints, assumptions, elements, and relationships)
2	*Slightly paradigm-stretching* Solution integrates an uncommon element or uncommon relationship between common elements, but still stays within constraints defined by the problem as given and typical assumptions	Highlights the elements and relationships central in two of the prior frameworks (Dean et al., 2006; Nagasundaram & Bostrom, 1994), but combines both into a single category
3	*Paradigm-stretching* Solution violates a constraint defined by the problem as given or a typical assumption	Utilizes language of constraints and assumptions to make explicit aspects of the more paradigm-modifying categories from the Gryskiewicz (1980) framework
4	*Paradigm-breaking* Solution shifts the focus of the problem to a larger problem	Utilizes language of problem focus to make explicit aspects of the most extreme paradigm-modifying categories from the Gryskiewicz (1980) and Dean et al. (2006) frameworks

Table 3 General paradigm-relatedness component-based metric.

Component	(1) Paradigm-Preserving [PP]	(2) Paradigm-Modifying [PM]
Elements	The idea uses elements that are commonly found in or associated with this type of problem.	The idea uses elements that are not commonly found in or associated with this type of problem.
Relationships	The idea maintains expected ways that a user would interact with elements in this type of problem, and maintains expected ways that elements interact with each other.	The idea proposes an unexpected way for a user to interact with elements in this type of problem or proposes an unexpected way for elements to interact with each other.
Constraints (and Assumptions)	The idea works within the underlying constraints and assumptions of the problem.	The idea alters the underlying constraints or assumptions of the problem.
Focus	The idea directly addresses the problem as given.	The idea focuses on a solution for a larger problem.
Overall	The idea has the overall impression of being more paradigm-preserving after considering the different components.	The idea has the overall impression of being more paradigm-modifying after considering the different components.

in influencing the overall paradigm-relatedness of an idea than the others? Like the category-based metric, the resulting component-based metric captured the critical theoretical aspects of all three prior paradigm-relatedness frameworks, but did so by utilizing an alternative approach to more explicitly differentiate the different aspects of paradigm-relatedness.

4. Preliminary testing of the alternative paradigm-relatedness metrics

The general descriptions of the categories and components of the alternative paradigm-relatedness metrics were designed with the intention of being adaptable to a wide range of different problem contexts. However, like the paradigm-relatedness metrics used in the literature, we expected that our two general paradigm-relatedness metrics would have to be tailored to the specific problem contexts in order to be reliably coded. Therefore, to test the generality of the underlying structure of the alternative metrics, we sought to apply them across multiple problem contexts and assess how easily they were adapted to the new design problems. The preliminary testing involved analysis of the inter-rater reliability of the different aspects of the coding scheme. The analysis resulted in determining which aspects of the alternative metrics worked well and which were in need of further development, and then led to suggestions for revisions of the metrics.

4.1. Preliminary testing methods

4.1.1. Generation of initial context-specific codes

To test our newly-developed metrics, we developed multiple design problem contexts, each of which had never previously been coded for paradigm-relatedness:

(1) *Belongings* – Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space.
(2) *Lids* – Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand.
(3) *Snow* – Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow.

The three problem contexts represent a range of design situations and were identified and developed through a process of examining design problems used in prior ideation research (Silk, Daly, Jablokow, Yilmaz, & Rosenberg, 2014; Yilmaz et al., 2015). We developed an initial application of the metrics that was tailored to each problem context through a careful reading of the problem statement to understand the explicit focus of the problem, the implicit constraints and assumptions, as well as the common elements and relationships that would be familiar to most people. Our intention was that this problem-context-specific application of the metrics would be updated iteratively as we engaged in coding of actual data. To illustrate the context-specific metrics, the full problem description and context-specific coding manual for the *Snow* problem are available in the online supplementary material.

4.1.2. Data sources

To test the revised category-based paradigm-relatedness metric and the alternative component-based paradigm-relatedness metric, we collected ideation data from a total of 227 students from eleven different classrooms. Five of the classrooms were sections of a sophomore-level mechanical engineering class at a large Midwestern university. One classroom was from a section of first-year undergraduate introduction to engineering at a different large Midwestern university. The other five classrooms were from a pre-engineering summer program at a third large Midwestern university for students entering tenth through twelfth grade who were interested in pursuing engineering at the undergraduate level.

The participants were randomly assigned to generate ideas for one of the three new problem contexts. They were given the problem statement on paper, along with blank idea sheets in which they

Table 4. Inter-rater agreement and reliabilities for the metrics by problem context.

	Belongings		Lids		Snow	
Metric	Agreement (%)	Cohen's Kappa	Agreement (%)	Cohen's Kappa	Agreement (%)	Cohen's Kappa
Category	87	0.78	91	0.82	94	0.88
Component						
Elements	93	0.84	91	0.68	88	0.75
Relationships	89	0.62	84	0.29	79	0.55
Constraints	94	0.89	94	0.86	97	0.89
Focus	99	0.85	100	1.00	97	0.87
Overall	88	0.42	95	0.75	92	0.76

recorded a drawing and verbal description of their ideas. They were instructed to record each idea on a separate idea sheet and were given twenty minutes to generate ideas independently. A total of 791 ideas were generated—75 participants generated 263 ideas for the *Belongings* problem context, 76 participants generated 267 ideas for the *Lids* problem context, and 76 participants generated 261 ideas for the *Snow* problem context.

4.1.3. Coding procedure

Two undergraduate research assistants coded the ideas. The ideas were blinded and randomly ordered to minimize the ability of the coders to tell which ideas the same participant generated. There were three phases to the coding: (1) training, (2) application, and (3) consensus. In the training phase, coders engaged in multiple rounds of coding and discussion on a subset of 10% of the ideas from each of the problem contexts in order to gain a shared understanding of the paradigm-relatedness codes. Through discussion of disagreements among the coders and a more senior researcher (the first author), we clarified and added to the coding manual for each of the paradigm-relatedness codes. When the coders achieved a shared understanding of how to apply the metrics, they moved onto the application phase in which each rater coded the full set of ideas independently. These independent codes on the full data-set were used to determine the inter-rater reliability of the metrics. In the final phase, the two coders discussed all disagreements, and created consensus codes for each disagreement. The final consensus codes would be suitable for use in research beyond the present study as measures of paradigm-relatedness.

4.2. Preliminary testing results

4.2.1. Inter-rater reliability

The first step in evaluating the usefulness of the alternative paradigm-relatedness metrics was determining to what extent the two coders reliably applied the metrics. An agreement percentage and Cohen's kappa (Cohen, 1960) for each independent code are reported in Table 4. Percent agreement was calculated as the total number of ideas coded identically by both raters divided by the total number of ideas coded, then multiplied by 100%. Cohen's kappa was calculated according to the following formula: $\kappa = [P(a) - P(e)] / [1 - P(e)]$, where $P(a)$ represents the proportion of ideas coded identically by the two raters, and $P(e)$ represents the proportion of ideas for which agreement between the raters was expected by chance. The chance agreement was based on the observed frequencies of the codes in the data-set. The Cohen's kappa value represents the proportion of agreement between raters after chance agreement has been removed, and so is a stricter measure of agreement than percent agreement. We evaluated the strength of agreement between the raters using qualitative benchmarks as defined by Landis and Koch (1977).

The category-based metric had high inter-rater agreement (substantial or almost perfect) for all three problem contexts, suggesting that the categories were relatively straightforward to apply to the ideas. The inter-rater agreement was more mixed with the component-based metric. *Focus* and

Constraints had almost perfect agreement in all of the contexts. *Elements* did not have as high an inter-rater agreement, but the agreement was still generally good, with some variability between substantial and almost perfect across the problem contexts. However, *Relationships* and the *Overall* code both varied between substantial and moderate inter-rater agreement across the problem contexts, and *Relationships* even had only a fair agreement in the *Lids* problem context. These lower levels of inter-rater agreement on some of the components and not others, suggest that there may be fundamental challenges in coding those particular components reliably.

4.2.2. Ease of use

In order to evaluate whether the alternative metrics could be used broadly, we considered the ease of use of each metric in terms of how long it took to develop the context-specific versions for each metric and then to apply them to a large data-set. As described earlier, in the training phase of the coding process, the two coders discussed their codes of the initial subset of data together in an attempt to clarify the codes before coding the full data-set independently. The context-specific metrics were updated based on these discussions. It often took multiple rounds of coding and discussion in the training phase in order to minimize the prevalence of disagreements on just the smaller subset of data sufficiently enough to justify moving onto the formal testing phase with the larger data-set. The category-based metric and the *Constraints* and *Focus* components in the component-based metric generally took only two or three rounds of discussion to achieve a sufficient level of agreement on the smaller subset of data. However, the *Elements*, *Relationships*, and *Overall* components in the component-based paradigm-relatedness metric took between four and six rounds of discussion in the training phase before we felt there was sufficient agreement to move onto the application phase. Still, even after the extended discussions in the training phase, we were not able to obtain adequate inter-rater reliability in the application phase for the *Relationships* component two of the problem contexts. Given that *Relationships* was proposed as part of Nagasundaram and Bostrom's (1994) theoretical framework but not coded independently in any of the prior research, this may be because assessing typical versus atypical relationships between elements is difficult to determine. Other aspects of the paradigm-relatedness codes, including *Constraints* and *Focus*, and to some extent *Elements,* may be easier to determine given the ease with which we obtained a sufficient level of agreement.

We did not observe any speed-ups as we trained new coders, even when the new coders were paired with previously-trained coders, or as we transferred the same general metrics to new problem contexts. That is, a previously-trained coder working with a coder who was in the training phase for the first time would still require at least two or three rounds of discussion to achieve a sufficient level of agreement between them. And those rounds of discussions continued to be necessary as we moved from coding one problem context to another for both the category- and component-based metrics. The lack of speed-up suggested that being able to apply the paradigm-relatedness metrics reliably was more the result of understanding the specific ways in which the codes applied to one context or another, rather than learning general principles that underlay the metrics and that could be applied broadly.

Another way to compare the ease of use of the alternative paradigm-relatedness metrics was to consider the amount of time it took to code the full set of ideas after training. The coders reported that they could generally code about two hundred ideas in two hours using the category-based metric, but two hundred ideas would require about four hours when using the component-based metric. This is not surprising given that the category-based metric contains only one code, whereas the component-based metric contains five codes. Despite the relative number of codes in each metric, the category-based metric was only about twice as fast rather than a full five times faster. The component-based metric certainly does force the coder to consider more aspects of each idea, although the additional codes are not entirely independent of each other as some time must be devoted just to understanding the idea regardless of how many codes are applied.

4.2.3. Examples

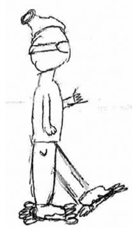
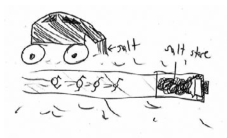
Table 5 includes four examples of *Snow* ideas from the data-set to illustrate how the paradigm-relatedness coding was applied and the usefulness of the different metric approaches to differentiate the ideas with respect to paradigm-relatedness. We chose examples to illustrate the range of ideas that are generated with respect to paradigm-relatedness, so there is one example of each of the category codes. For each example, we include the participant's own drawing and description.

The *Snow-Slides* idea was a prototypical paradigm-preserving solution. The solution resembles snowshoes, which is a common solution for individual transportation on snow. In addition to being coded as *Paradigm-Preserving* for the category-based metric, each of the components were also coded as *Paradigm-Preserving*. The solution still appeared workable and made an adaptation to existing snowshoes to make them more suited for everyday transportation, but the solution approached the problem as it was given. The *Bounce Skis* idea moved in the direction of paradigm-modifying, although was still coded predominantly as paradigm-preserving. This solution was coded as *Slightly Paradigm-Stretching* for the category-based metric, because the use of a spring was not an element typically utilized in snow transportation. Consistent with the category-based metric, the component-based metric resulted in coding this idea as *Paradigm-Modifying* for the *Elements* component, even though the *Overall* component-based code was still *Paradigm-Preserving*. For these first two ideas, the category-based metric and the component-based metric were consistent with each other, as the use of the uncommon element (springs for bouncing) was reflected both in the *Elements* component coding and in the *Slightly Paradigm-Stretching* category code.

We saw some distinctions between the category-based metric and the component-based metric in the third and fourth ideas. The *Snow Melter* was coded as *Paradigm-Stretching* because the idea violated a typical assumption in the problem that the snow must be more or less left in place. We determined that heating was a common element in snow transportation and so the idea was *Paradigm-Preserving* in the *Elements* component. However, the placement of the heaters on the individual's hands was uncommon and so this idea was coded as *Paradigm-Modifying* for the *Relationships* component. The idea maintained the initial focus of the problem as the idea still approached the problem by proposing a solution for an individual to control. The *Salt and Steam Roller* was coded as *Paradigm-Breaking* in the category coding as the solution made use of a shared infrastructure, the roller, which cleared the path for individuals behind it. This shared approach also resulted in a *Paradigm-Modifying* code for *Focus* because the solution essentially re-framed the problem from one requiring an individual transporter to a larger problem about the ways communities support transportation generally. The idea also illustrates some of the challenges in differentiating *Elements* versus *Relationships*. The idea was coded as *Paradigm-Modifying* for *Elements* and not *Relationships*, because the coders determined that although a steam roller was not an element commonly utilized in this type of problem, the steam roller was used in a way that might be expected given its typical functions. That is, even though the element itself was paradigm-modifying, its use within the solution was not. One distinction between the category- and component-based metrics was that the categories do not always indicate whether an element was used in a paradigm-modifying way or whether the relationships between elements were paradigm-modifying. Our experiences using the component-based metrics also helped us to understand better what constituted an *Overall* paradigm-modifying code. Paradigm-modifying elements on their own were generally not sufficient to warrant an *Overall* paradigm-modifying code, but relationships, constraints, or focus generally were, as were various combinations of components. Thus, it was useful to have the *Overall* paradigm-relatedness code and relate that overall code to the different components, because it helped to understand the diversity of ways in which an idea could be paradigm-modifying.

In general, the category- and component-based paradigm-relatedness metrics were well aligned with each other. The categories, in their definitions, roughly correspond to the different components of paradigm-relatedness. However, the component-based metric was more explicit about which particular components were paradigm-modifying. When comparing ideas within a category, it may be possible that some ideas made use of paradigm-modifying elements, others made use of paradigm-modifying

Table 5. Example ideas and their consensus paradigm-relatedness codes.

Idea	Drawing	Description	Codes	
1. Snow-slides		These snow-slides can slip on any book, shoe, foot and can stay on the snow due to its flat surface	Category: *Component* Elements: Relationships: Constraints: Focus: Overall:	1 1 1 1 1 1
2. Bounce skis		In this idea, I created bounce skiis. It is fun and very easy to learn. Because you would be bouncing and the coils would be strapped to the skiis. You can go up the hill bouncing and down the hill bouncing. Features coils, springs, skies, skii sticks. It would be entertaining for the fun learners, and it would be easy because your just bouncing everywhere	Category: *Component* Elements: Relationships: Constraints: Focus: Overall:	2 2 1 1 1 1
3. Snow melter		- Attaches into arms - It is a device that blows very hot air onto the snow, causing it to melt instantly, allowing a person to walk through - Uses heaters	Category: *Component* Elements: Relationships: Constraints: Focus: Overall:	3 1 2 2 1 2
4. Salt and steam roller		Cleans path for other vehicles behind it. It steam rolls after salt has been added before it, allowing any other people to skate on the new made ice	Category: *Component* Elements: Relationships: Constraints: Focus: Overall:	4 2 1 2 2 2

relationships, and other ideas used both. Utilizing the component-based metric to look across the ideas generated by a single individual may provide a more comprehensive assessment of the range of components that the designer considered. In other words, even if the individual generated ideas that spanned the different categories, there may still be some components of paradigm-relatedness in the broader solution space that he or she did not fully explore. As a result, the component-based metric may provide more explicit information to guide the individual in expanding the diversity of his or her ideas. Still, the category-based metric provides much of that information in just one code, and so approximates the component-based metric reasonably well.

5. Discussion and conclusion

We set out to better understand how paradigm-relatedness could be utilized as a guide for exploring creativity and diversity in ideation. Paradigm-relatedness highlights different ways for a designer to be creative and diverse, independent of the usefulness or novelty of his or her ideas. In particular, paradigm-relatedness refers to the transformational dimension of an idea—whether the idea represented more incremental change or more radical change with respect to typical ways of approaching or conceptualizing a problem (Besemer & Treffinger, 1981; Boden, 2004; Grace & Maher, 2015). Our analysis of the literature on ideation metrics (Dean et al., 2006) made the case that paradigm-relatedness is currently the only ideation metric available that is a measure of creative style rather than creative level (Kirton, 2011), an important contribution to the literature on creativity metrics (Amabile, 1996; Besemer & O'Quin, 1987; Brown, 2014; Dean et al., 2006; Kudrowitz & Wallace, 2013; Oman et al., 2012; Plucker et al., 2004; Sarkar & Chakrabarti, 2011, 2015). As such, paradigm-relatedness may be uniquely positioned to help designers assess the extent to which they have considered the full range of possible approaches or conceptualizations of a problem in their ideation process (Boden, 2004; Grace & Maher, 2015).

Our synthesis of theoretical frameworks of paradigm-relatedness (Dean et al., 2006; Gryskiewicz, 1980; Nagasundaram & Bostrom, 1994) led to our development of a revised framework that built on the similarities of those prior frameworks, while also being more explicit about incorporating the different components of paradigm-relatedness on which they were based. As a result, our revised framework made salient *elements* and *relationships*, *constraints* and *assumptions*, and *focus*—each as components of paradigm-relatedness that should be considered altogether in any thorough discussion of paradigm-relatedness. Additionally, based on our review of empirical studies that utilized paradigm-relatedness (Dean et al., 2006; Garfield et al., 2001; Gryskiewicz, 1980; Nagasundaram, 1995; Satzinger et al., 1999) that revealed paradigm-relatedness is often operationalized as a set of categories, we developed two alternative paradigm-relatedness metrics—one category-based and the other component-based—that we specified in general terms. We then also developed context-specific versions of the metrics for design problem contexts that had not been used with paradigm-relatedness research before.

The process of developing the context-specific versions of the category-based metric helped us to recognize how critical the components of paradigm-relatedness were in defining the boundaries between categories. The implication is that to develop a category-based metric for any new problem context, the developer must understand the particulars of that problem situation enough to determine the common elements and relationships, the typical constraints and assumptions, and the potential for focusing on a larger problem than the one given. Thus, even if the category-based metric aligned best with what had been utilized in prior empirical studies utilizing paradigm-relatedness, the component-based metric served as the foundation from which the category-based metric was built.

Applying the context-specific versions of the alternative metrics to a data-set of ideas highlighted the advantages and disadvantages of the two approaches. The category-based metric was relatively easy to obtain inter-rater reliability and was faster to apply across a larger data-set of ideas. The categories themselves also make salient key differences along the paradigm-relatedness spectrum, but did so at a coarse level. In the component-based metric, there were particular components that were difficult to obtain adequate inter-rater reliability and more time was required to code each of the different components for each idea. However, an advantage of the component-based approach was that it made explicit the particular aspects of ideas that determined where along the paradigm-relatedness spectrum those ideas were located.

5.1. Limitations

One limitation of our work is that we were not successful in obtaining high inter-rater reliability on a number of the components of the component-based metric, specifically *Relationships*. Future work may result in a better specification of what is meant by relationships so that that component can be understood and applied consistently across a broad set of ideas. Additionally, as this work was focused on development and trade-offs between theoretical alignment and practical implications, we are not yet to the stage of a full-scale experiment on the metric. Future work will include empirical tests of our claims that the metrics developed here are useful for assessing ideation creativity and diversity. Our analyses were based on an extensive review and synthesis of the available literature and a careful reflection on our own experience developing and applying the metrics. Future work should also consist of applying the metrics in design, teaching or research settings that investigate the relationship of paradigm-relatedness to other valued processes and outcomes of ideation. We think that doing so will broaden and deepen the field by recognizing the different ways designers can be both creative and diverse in their ideation.

5.2. Implications

We conjecture that the category-based metric approach is best suited for assessing larger sets of ideas because it is faster to apply and more reliable. Researchers interested in studying ideation creativity and diversity can employ the category-based metric in multiple ways. For example, the category-based metric could be used to describe the distribution of ideas in different situations, such as whether one ideation approach results in a greater percentage of paradigm-modifying ideas versus another. The category-based metric can also be used to test the effect of an intervention on ideation diversity by examining whether the ideas are spread out across the categories versus more concentrated in a particular category. Teachers or professionals may also benefit from using the category-based metric since it might be easier for students to learn to apply more quickly. However, we caution that the category-based metric will likely only be easier to apply in problem contexts in which the categories have previously been defined. In new problem contexts, our experience suggests that the design researcher, teacher, or professional must spend considerable effort thinking about how the components of paradigm-relatedness can be translated into the different categories. We hope that our description of the analysis and process of developing the alternative paradigm-relatedness metrics in this paper can serve as the basis for other design researchers, teachers, and professionals applying paradigm-relatedness to a wide range of new problem contexts.

The component-based metric, however, does still have potential advantages on its own. Professionals taking the time and effort to ideate around a small set of problems that they can explore in depth may benefit from considering the components separately and together to assess how well they have explored the solution space. The component-based metric makes more salient the different ways to think about paradigm-relatedness, and so might help a design professional to identify particular types of ideas that differ from their existing ideas along one or more of those components. Researchers may also benefit from the component-based approach when doing more in-depth analyses of cases of ideation. In sum, the component-based approach may be better suited for smaller-scale, more in-depth assessment of ideation, whereas the category-based approach may be better suited for larger-scale, more broad-based assessments.

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