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DOES DESIGN RATIONALE ENHANCE CREATIVITY?

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Abstract: *Creativity and rationale are often viewed as two contrasting facets in software design. A lack in recognizing the facilitative relationship between creativity and rationale not only underestimates the benefits designers can obtain from rationale practices, but also confines the approaches that support creativity in software design. Our exploratory study provides empirical evidence of the positive correlation between rationale and creativity. Furthermore, we found that the feasibility of design alternatives and the comprehensiveness of tradeoff evaluation are critical to enhancing novelty, persuasiveness, and insightfulness. We also discuss future directions to further understand how these properties, or rationale quality in general, affects design creativity.*

Keywords: *design rationale, creativity, software design, quality, empirical study.*

INTRODUCTION

Creativity is often desirable in design activities. In order to create innovative artifacts, designers and design teams need to generate novel ideas, the originality and usefulness of which should be recognized and appreciated by others. In solving ill-defined complex problems, like software design and development, such creativity can hardly be achieved solely by individuals' one-shot or random thoughts, but requires designers to keep track of what has been done and why that has been done.

Design rationale can help keep track of those activities and reasons. Moreover, it can provoke designers to analyze and evaluate their design critically. These critical thinking processes are crucial to design creativity. However, we do not advocate capturing every detail of the design process in rationale. Indeed, that extreme form of design rationale is often criticized for the tedious work involved.

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Overemphasizing the cost of articulating design rationale will disguise the relationship between rationale and creativity as pure contrast. Instead, by focusing on the benefits of design rationale, the integrative potential between the two may emerge. Therefore, our study aims at bridging the gulf between rationale and creativity in software design by exploring why and how rationale and creativity can be mutually facilitative. Design rationale delineates the assumptions behind the questions in design. It may further stimulate designers to problematize design options and reframe or recreate design. By critically evaluating options, designers may create new possibilities to augment the strength and attenuate the weakness of current options. They may also make more rational decisions by converging on an option. However, such a statement has not been fully verified by theories, or by empirical studies. Our study is an empirical attempt to examine the relationship between rationale and creativity, and, in the long term, to understand how to support creativity by design rationale.

Following the presentation of the conceptual background, we will describe our study's context and design. We then will present the results, followed by an interpretation and discussion of those results and a reflection upon the whole exploratory study. We conclude with a discussion of future work.

CONCEPTUAL BACKGROUND

Design rationale is often characterized from various perspectives (Shipman & McCall, 1997). Instead of recording every detail of design processes, our view of design rationale focuses on reasoning and argumentation. From this perspective, design rationale emphasizes the articulation and representative reasoning underlying design (Fischer, Lemke, McCall, & Morch, 1991; Moran & Carroll, 1996; Buckingham Shum & Hammond, 1994). Argumentation-based design rationale attempts to stimulate designers to think and discuss design within a structured or semistructured representation. For example, in QOC (MacLean, Young, Bellotti, & Moran, 1991), questions are framed to pose key issues in the design, options are proposed as possible alternative solutions to the questions, and criteria are bases for reasoning and evaluating the options so as to choose among them. Argumentation-based design rationale is also illustrated in the task-artifact framework (TAF; Carroll & Rosson, 2003), in which tasks are represented as scenarios of use and claim analysis, enumerates the features of a system being used and their upsides and downsides of consequences. Many other endeavors have been invested to capture design rationale with such purpose: for example, an issue-based information system (IBIS; Kunz & Rittel, 1970) and its variants (gIBIS, Conklin & Yakemovic, 1991; PHI, Fischer et al., 1991), three extensions of IBIS (Potts, 1996), and DRL (Lee & Lai, 1991). By adapting notations from these, we will investigate whether and how design rationale facilitates evaluation abilities and critical thinking, and further affects creativity in software design.

The use of argumentation-based design rationale has been investigated in terms of both its benefits and costs (see the review in Buckingham Shum & Hammond, 1994). Despite the distraction and difficulty in externalizing design rationale into one semistructured form (Fischer et al., 1991; Buckingham Shum, 1993), empirical studies have shown evidence that in the design domain (a) argumentation-based design rationale can facilitate reasoning by augmenting both the product and process (Bellotti, 1993; Burgess-Yakemovic & Conklin, 1990; Buckingham Shum, 1996; Buckingham Shum, MacLean, Forder, & Hammond, 1993), and (b) an existing

argumentation-based rationale of earlier design is useful for both the owner and others (Conklin & Yakemovic, 1991; McKerlie & MacLean, 1994; Buckingham Shum, 1993). Studies have indicated that design rationale is particularly beneficial when it is applied to driving construction, to facilitating breadth-first exploration, and to early stages of design when less abstract externalization is required. Other than evaluating design rationale for its usefulness, research on the use of argumentation-based rationale also invested great efforts in the usability of its notation and representation (see the review in Buckingham Shum & Hammond, 1994), which is beyond the scope of this paper. However, of all the empirical work, none has reported any direct assessment of the quality of design rationale itself that we could build on.

Creativity is also conceptualized in various ways. Although it is sometimes regarded as mythical and unable to be explained, or as a revolutionary innovation that rarely happens, we consider creativity to be embedded in everyday activities and their social contexts (Amabile, 1996; Csikszentmihalyi, 1996; Gardner, 1993), which may have more implications for education and engineering practices. Even from this perspective, creativity can be characterized in many different ways, among which three features were tapped for our study of creativity measurement. Novelty is the most agreed aspect of creativity (Mayer, 1999; Sternberg, 2006; Sternberg & Lubart, 1991). It implies originality, such as new ideas. With regard to its social context, creativity requires the ability to persuade others the value of the work (Sternberg & Lubart, 1999) so as to be accepted by the field (Csikszentmihalyi, 1999). In our study, persuasiveness as a metric of creativity is assessed by examining the interim product of software design, that is, the rationale documents, with respect to the argumentation elaborated within them. Though insightful thinking cannot guarantee creative design, it is indispensible during the analytical design processes, ensuring powerful critical thinking. Without such scrutiny, novel ideas may not work eventually. The three dimensions of creativity operationalized in our study—novelty, persuasiveness and insightfulness—are expected to demonstrate the three intellectual abilities required to achieve creativity: synthetic ability to see problems in new ways and to escape the bounds of conventional thinking, analytic ability to recognize which of one's ideas are worth pursuing and which are not, and practical-contextual ability, to know how to persuade others of—or to convince other people of—the value of one's ideas (Sternberg, 1985).

The connection between design rationale and creativity in our view derives from the role of rationale in evoking critical thinking, which is often conceived as indivisible from creative thinking. In particular, evaluation abilities are crucial to creative thinking. Runco (1992) and Houtz, Montgomery, Kirkpatrick, and Feldhusen (1979) examined evaluation abilities in creative thinking, and both studies concluded that evaluative abilities play a significant role in creative functioning. Guilford (1967) also assigned an important role to evaluation ability in his models of creative thinking and problem solving.

However, research has been sparse with regard to the integrative potential of rationale and creativity in software design. Ball, Lambell, Ormerod, Slavin, & Mariani (2001) proposed that design rationale can provide insights into how best to represent and retrieve design knowledge in order to support innovative design reuse. They developed a design reuse system, Desperado II, to elicit and retrieve design rationale. By comparing the performance of the Desperado group and a control group, they found that the Desperado group considered up to three times as many options per question as the control group, and up to six times as many criteria. They claimed such performances as evidence that Desperado encourages innovative design, even though the increased number of options and criteria were not examined in terms of their

quality. Even if it is validated that Desperado can assist in overcoming satisficing tendencies and confirmation biases, their results only demonstrate that the representation of design rationale in Desperado can support creative design better than previous notations. It cannot explain the underpinning relationship between design rationale in general and creativity. Fischer (2004) argued that temporal barriers should be overcome to support social creativity. In a long-term design project, creativity can be supported by recording design rationale with minimal efforts and by providing a search utility to retrieve rationale easily. However, their paper did not provide much detail about empirical validation of this claim.

CLASSROOM STUDY

As a preliminary step to explore the relationship between rationale and creativity in software design, we conducted a classroom study that lasted for a whole semester. The design processes involved in such educational setting may not be exactly the same as those of professional designers, for instance, in terms of the process complexities. Nonetheless, the problem-solving practices in our study can still be creative in ways similar to those in professional work settings, especially the roles of reasoning and reflection throughout the entire design process. Moreover, all participants were assigned the same tasks without any other direct manipulation because of the ethical concerns in the educational setting. With particular interest in group collaboration, we asked participants to work on the tasks in groups, while we did not require them to communicate with each other through a particular medium.

Our study context lends itself to directly explore the relationship between rationale and creativity in software design. First, this naturalistic setting allows more flexibility to observe more than one property of design rationale that may influence creativity and to discover multiple ways, if there are any, in which the influences occur. Second, the benefits of articulating rationale on critical and analytical thinking cannot be achieved in a fabricated task that lasts only for a couple of minutes. Participants in our study carried out the task of articulating rationale during their real design practices over the semester.

Research Questions

As speculated in the workshop manifesto[1] (Carroll, 2009), creativity and rationale could have a mutually facilitative relationship. In this empirical study, we focused primarily on one direction of that relationship, that is, the effects of rationale on creativity in software design. More specifically, we wanted to examine whether rationale can play a positive role in enhancing creativity in software design and how. Therefore, we proposed the following research questions to guide our exploration.

Research Question 1: Does Better Quality Design Rationale Lead to More Creative Software Design?

Design rationale can be classified as prospective and retrospective (Carroll, 2009). People have different perspectives and thus different representations and usages of design rationale. From our view, the greatest potential for integrating rationale and creativity is in the activities

of constructing and articulating rationale during software design process. Rationale developed in such scenarios can be regarded as prospective because it is generated within the design activities and enables further software development. By creating and capturing rationale themselves, designers can benefit from their own efforts rather than recording the processes for others. Rationale of this kind can facilitate designers framing the problems, evaluating and problematizing alternative solutions, and then approaching the optimal decision. It could also convey the usefulness and value of the design to other people. It may even surface more design options or new design solutions. Therefore, high quality design rationale should enhance designers' reasoning and critical thinking, and thus their creative thinking and creative design. In contrast, retrospective design rationale affects the ongoing design process less and costs more recording efforts.

Research Question 2: What Properties of Design Rationale are Critical to Enhancing Creativity of Software Design?

Other than demonstrating the facilitative effect of rationale on creativity, the manner in which design rationale can enhance creativity is even more important to design tools that support creative design, improve education in software development, and manage innovation of system development in organizations. Since design rationale consists of multiple elements involving a variety of quality characteristics, it is plausible to explore what properties of design rationale, with respect to quality, are critical to creative design.

Not every property of design rationale has positive influences on creativity. As the conventional view on the relationship between rationale and creativity implies, there is inevitable tension between these two concepts. Functioning as documentation, rationale may confine creativity by restraining divergence or adventure. Therefore, some properties of rationale may be valued in terms of rationale quality but not promising for fostering creativity.

Additionally, analyzing creativity from process perspective is compelling given our special interest in group collaboration. This research question focuses on the creative abilities of persons involved and creative characteristics of design products. However, design rationale, as a means to communicate and facilitate discourse, may impact the creative design processes of the group. Therefore, we proposed the following research questions with respect to groups' collaborative processes.

Research Question 3: What Properties of Design Rationale Will Enhance Creative Design Processes of the Group?

Other than mutual facilitative correlation, it is also important to understand the causal effect from design rationale to creativity, meaning, why and how design rationale can evoke and foster creativity. Thus investigating creative processes may shed light on an underpinning relationship between the two. Group creativity requires divergent thinking, convergent thinking, shared information and objectives, and reflexivity (Farooq, Carroll, & Ganoe, 2005). The first impression of the integrative relationship between rationale and creative processes is that the evaluative thinking evoked by rationale might facilitate reflexivity and convergent thinking of the group. Claims (Carroll & Rosson, 2003; Lee & Lai, 1991), criteria (MacLean, Young, & Moran, 1989), or arguments (Kunz & Rittel, 1970) motivate designers

to examine design options rationally so as to approach the optimal decision. Furthermore, they provide opportunities to amplify strengths and ameliorate weaknesses of the final solution. Prospective rationale can assist groups with planning the design implementation, while retrospective rationale can offer traceable records for designers to ruminate over previous decision making processes or other people's reasoning trajectory so that group members can further refine an old design or create a new one. However, such impression might underestimate the potential of rationale influencing creative processes. By questioning design options with persuasive claims, rationale might inspire more alternative solutions to overcome the downsides of current ones. It may also evoke new ideas by improving designers' understanding of the total problem, or by bringing more opportunities for designers to encounter unexpectedness. Therefore, investigating how rationale affects creative processes other than the final product is needed.

> Research Question 4: How Will Sharing Design Rationale Across Groups Influence a Group's Creative Design Processes?

Design rationale is not just used by its creators for the current design practices, but also visited after the design cycle by both its creators and other people outside the design team. Although people are motivated by different purposes to comprehend rationale documents (e.g., reusing and adapting the design, creating new design, or even are not motivated), design rationale makes it possible to communicate with the software designers about what was going on and why. By collaboratively making sense of rationale, designers may reach a shared understanding effectively and acquire insights into their own design problem and possible solutions. Moreover, open information exchange across organizational boundaries is an important determinant of creativity (Henry, 2004; Woodman, Sawyer, & Griffin, 1993). Design rationale, as one type of information shared between groups, may also augment groups' information sources, introduce flexibility, and open new opportunities. Despite more effort required to take advantage of such rationale, groups will obtain better chances for learning and cooperation. All of the benefits from intergroup sharing of rationale are possible but need to be examined.

Participants

Participants were undergraduate students majored in computer and information sciences in an advanced object oriented design and software course. The advanced course required prerequisite courses, including one introducing general computer languages and another on a specific computer language (either Visual Basic or C++). Thus all of the participants had basic knowledge and experience to some extent in software design before our study. The course had two sections taught by different instructors. Participants came from both sections and shared the same syllabus and class activities. The 49 students participated in our study by voluntary consent. 3 of them are female and the other 46 are male.

Task Description

The task required participants to solve specific design problems by capturing design rationale and implementing the design by Java. It was integrated into every lab programming

assignments of the course over the semester. Each lab assignment specified the goal of design that students should achieve. For example, one assignment asked students to implement a graphical user interface to support a decision model given by the instructor. Students had more than a week to work on each assignment. In the middle of each assignment, they were asked to submit their design rationale as their progress reports, which were counted as part of their grades. After students had turned in their implementation towards the end of each lab, the instructors showed their own solution.

The design problems of each lab assignments allow students to act creatively. Although these assignments are generally close-ended, they do not confine the students' approach to the problems along a single definite path. Therefore, participants had the opportunity and enough flexibility to perform creatively. Furthermore, all of the lab assignments were related to each other, contributing as a component to a complete project. Specifically, the later tasks were supposed to be built upon the earlier ones. This may facilitate students' reuse of prior designs.

We set the submission time of design rationale a few days before that of implementation. We expected this time arrangement could enable design rationale to facilitate students in thinking critically. Based on our hypothesis about the relationship between design rationale and creativity, such prospective design rationale created during design processes should drive the construction as well as augment the reasoning and reflection of its owners. When it is used by other people, it may also have similar benefits for them.

Design rationale documents were specified in a uniform format for all the students of the course. To minimize the overhead of recording rationale, we simplified its representation into four components, including (a) the toughest design problems you are facing or did face, (b) the design alternatives for solving these problems, (c) the pros and cons for each alternative, and (d) what option you are leaning towards (the decision on alternatives). These elements are consistent with those of other methods, such as IBIS (issues, positions and arguments; Kunz & Rittel, 1970) and QOC (questions, options, and criteria; MacLean et al., 1991). Since it was not a topic in the curriculum, the instructors explained what benefits design rationale could bring to software design, such as keeping track of the design state. They further illustrated design rationale by a sample. The sample presented design rationale for a concrete design problem in the format that students were required to use. Because this representation is not highly abstract but rather more narrative, the students did not find difficulty in articulating rationale in this way. Students were already familiar with externalizing design rationale in the way we defined since we did not start our analysis until their third lab assignment.

From the third lab assignment, students also began cooperating on their lab assignments in pairs or triads. Each team had to submit only one design rationale and one implementation for each assignment. No particular medium was specified for their communication and collaboration. They chose teammates by themselves but could not pick the same person more than once. They were also given a short time in class to collaborate with their team member(s) on these assignments. In other words, their initial collaboration was face-to-face, although they also might have communicated virtually sometimes. Such rotated pairing may better motivate students to share design rationale across groups because each student in the group can serve as a boundary object (Fleischmann, 2006) between his or her prior and current design. Intergroup information exchange is likely to happen when there are people who have sufficient knowledge of practices of both groups (Henry, 2004).

Data Collection

Data collected in our study comprised two parts: (a) an assessment of design rationale quality and design creativity; and (b) the responses to surveys with respect to design collaboration. The first part was mainly gathered to answer research questions 1 and 2 (i.e., the relationship between rationale quality and design creativity). The second part was used to address research questions 3 and 4 (i.e., the effects of rationale quality on perceived creative processes). Data were sampled from three out of all the lab assignments of the course: one was at the beginning of the semester when they just started to work in teams (i.e., the third lab assignment); one was in the middle of the semester, and the other was at the end. Surveys were disseminated immediately after rationale submission for each of the three lab assignments. The number of respondents varied across the three assignments, based on their own voluntary decision. The assessment on design rationale quality and creativity was conducted with the criteria we developed (see Appendix for details) by two teaching assistants.

To investigate the relationship between rationale quality and design creativity, we developed criteria for evaluating design rationale documents in terms of these two focuses. Design rationale and creativity are each comprehensive concepts with various perspectives. Because, as noted in the previous section, no established evaluation scales can be directly applied in examining our specific data, the three authors brainstormed and decomposed rationale quality and creativity into measurable dimensions, respectively.

Judging rationale quality (6 dimensions) encompassed concerns for each element in the design rationale representation we developed, that is, problems, alternatives, tradeoffs, and decision. The overall quality of the rationale as a communication tool was also operationalized as *clarity of articulation* criteria. Problem identification and definition is critical to all the effort involved in problem-solving activities, determining the level of critical thinking (Garrison, 1992; Henri, 1991). Given the problem-solving nature of software design, identifying and defining the design problem are also important in articulating design rationale. These require critical thinking. Moreover, problem-solving influences the quality of other elements in design rationale as well, such as how well the proposed alternatives address the design problem, and whether the decision made is wise. Thus, in our rationale quality evaluation, we asked for judgment on whether the statement of design problem captured a critical issue of the design task (i.e., *toughest design problem identification*). Alternatives are the possible solutions designers generate to tackle the problem. Good alternatives should be able to the design issue as a solution candidate (i.e., *relevance of alternatives* in our evaluation criteria; see Appendix). Furthermore, they should provide not only conceptual guidance but also feasible ideas, since software design is expected to lead to practical results. Therefore, we employed *feasibility of alternatives* in our assessment. Specifically, we customized the definition of feasibility by students' programming ability acquired from the course. Tradeoffs are articulated when designers justify or problematize their alternatives. Maintaining high quality of tradeoffs requires exploring a wide range of possible consequences of a design alternative. Analysis from a single perspective may bias designers' judgment of an alternative. *Comprehensiveness of tradeoffs* in our criteria aimed at addressing this requirement of rationale quality. One outcome of critical thinking involved in design rationale articulation is the decision, namely the final problem solution to be implemented. The quality of the *decision* indicates the performance of analytical work engaged in design rationale documents. Thus, we included this dimension by asking whether the design alternative selected is the optimal solution in

our evaluation criteria. As an artifact for communication purposes, clarity also represents the quality of design rationale. Moreover, clarity implies how thoroughly designers have considered the design problem, alternatives, tradeoffs, and the decision. These metrics were not exhaustive but rather reflected an argumentation perspective that involves critical thinking. Relevance, ambiguities (clarity in our study), practical utility (feasibility in our study), and width of understanding (comprehensiveness in our study) are also identified as critical factors in the model of assessing critical thinking, which was developed by Newman, Johnson, Webb, & Cochrane (1997).

The rubrics for evaluating creativity (3 dimensions) in the identified problems solutions were adapted from Farooq's (2008) doctoral dissertation. Novelty as a common feature of creative ideas was maintained in the adaptation (i.e., *novelty of alternatives*). *Insightfulness of tradeoffs* was added to our rating dimensions because design rationale has the characteristic of analytical thinking, which was not externalized in the task of Farooq's study. We evaluated creativity by rating rationale documents instead of directly assessing students' code. The underlying assumption for this decision was that the students would solve the problem in the way they stated in their design rationale documents. Furthermore, the overall criteria do not evaluate creativity only from the final product perspective, but also indicate the creative capacity of designers that may not be explicitly codified in their product. For instance, *persuasiveness of tradeoffs* represents the designer's ability to persuade others of the value of his/her design, which is suggested to be an important dimension of creativity (Sternberg & Lubart, 1991).The judges who rated the design rationale quality and design creativity were the teaching assistants for the two sections of the course. They were considered to be qualified in several aspects: (a) both had advanced object oriented design experience; (b) they were very familiar with the tasks; (c) they knew the students' design expertise well; and (d) they had the closest interaction with participants, which may have assisted in their understanding and judgment of the students' design processes.

Both judges followed the same procedure to assess the submissions. Prior to implementing the study, we made sure the criteria were appropriate for the context of the course and study and executable for the judges to apply. We walked through the evaluation criteria with the judges, during which they interpreted the rubrics item by item to confirm that their comprehension was consistent with our intention. Then they independently evaluated every document based on their overall impression of the performance of the whole class, with rating scale from 1 (*very poor*) to 5 (*very good*). To prevent the order effect, the judges rated the first half of the students' rationale documents in the order of rationale quality to creativity, and the other half of documents from creativity to rationale quality. In the analysis, we averaged the scores rated by the two judges as the final assessment output.

Surveys were designed to complement our understanding of the collaborative design processes. They consisted of questions with respect to students' perceived creative processes by articulating rationale as well as their use and reflection on previous rationale. These questions were rated on a 9-point Likert scale. We also collected data about some demographic information and personal creative characteristics in the last survey at the end of the semester.

RESULTS

For the three lab assignments we collected, 27, 28, and 17 design rationale documents submitted by teams, respectively, were rated by judges, while 16, 16, and 14 responses to our

surveys by individuals, respectively, were collected. Since participants completed the surveys voluntarily, the number of responses was smaller than the number of design rationale documents that were consented to be analyzed. We conducted regression analysis on both data sets: one set included all 72 average ratings for the progress reports submitted; the other set included all 46 survey responses and the survey participants' progress reports (excluding the assessment scores for the students who did not fill out the surveys). In the analysis, properties of rationale quality were used as independent variables, and properties of creativity and ratings of perceived creative processes were set as dependent variables.

RQ1: Does Better Quality of Design Rationale Lead to More Creative Software Design?

All of the properties of rationale quality significantly positively correlated with the three aspects of creativity as indicated by Pearson correlation analysis. Furthermore, by using multiple regression analysis with stepwise approach, we found that the higher the quality of design rationale, the more creative the design, although the regression models suggested by the two data sets were slightly different. To be specific, for both data sets we performed stepwise regression on the three aspects of creativity the judges rated (i.e., novelty of alternatives, persuasiveness of tradeoffs, and insightfulness of tradeoffs) to select the properties of design rationale that affected these aspects individually. We also coded the lab number as independent variables in regression models to examine whether there was any confounding effect caused by the difference of lab assignments.

Given two judges performed assessment, interrater reliability was also tested on each criterion, as well as the entire rubrics. Comprehensiveness, persuasiveness, and insightfulness of tradeoffs had values of interrater reliability larger than the rule of thumb 0.7 (Cronbach's Alpha = Average Measures Intraclass Correlation Coefficient = 0.839, 0.736, and 0.794, respectively). Additionally, the overall creativity (novelty of alternatives, persuasiveness of tradeoffs, and insightfulness of tradeoffs) had fair interrater reliability (Cronbach's Alpha = 0.686, Average Measures Intraclass Correlation Coefficient = 0.674). The final three measurements did not achieve interrater reliability as high as these, and therefore could be decomposed or clarified more in the future to approach more agreement and consistency.

RQ2&3: What Properties of Design Rationale are Critical to Enhance Creativity of Software Design and How?

Regression analysis on the first data set indicates that two properties of rationale quality, feasibility of alternatives and comprehensiveness of tradeoffs, are crucial to enhancing design creativity. The first data set does not include any variables measured by survey responses but all the ratings on 72 design rationale documents. We built three models for each aspect of creativity with stepwise regression. Table 1 summarizes all these models for predicting the three aspects of creativity on the first data set. The model predicting novelty of alternatives is Novelty = 0.612 * Feasibility +0.238 * Comprehensiveness, $F(2, 69) = 97.88$, $p < .001$, $R^2 = .729$. The model for predicting persuasiveness of tradeoffs is Persuasiveness = 0.361 * Feasibility + 0.620 * Comprehensiveness, $F(2, 69) = 202.044$, $p < .001$, $R^2 = .854$. The model for predicting insightfulness of tradeoffs is Insightfulness = 0.254 * Feasibility +0.730 * Comprehensiveness,

Table 1. Relationship Between Rationale Quality and Creativity on the First Data Set (N =72).

Model	Quality of DR (IV 1)	Coefficient 1	Quality of DR (IV 2)	Coefficient 2	Creativity (DV)
1	Feasibility of Alternatives	0.612***	Comprehensiveness of Tradeoffs	0.238** (p = .001)	Novelty of Alternatives
2	Feasibility of Alternatives	0.361***	Comprehensiveness of Tradeoffs	0.620***	Persuasiveness of Tradeoffs
3	Feasibility of Alternatives	0.254* (p = .013)	Comprehensiveness of Tradeoffs	0.730***	Insightfulness of Tradeoffs

Note: Significance level: *** $p < .001$, ** $p < .01$, * $p < .05$

$F(2, 69) = 166.254$, $p < .001$, $R^2 = .828$. Although the determination of a reliable relationship in this analysis does not imply causality, it will increase our understanding of what properties of design rationale are important to foster creativity.

Moreover, the feasibility of alternatives has a stronger positive relationship with novelty of alternatives ($\beta = 0.612$) than comprehensiveness of tradeoffs ($\beta = 0.238$) according to the values of coefficients in each model above. Conversely, with persuasiveness of tradeoffs and insightfulness of tradeoffs, comprehensiveness of tradeoffs has a stronger relationship than feasibility of alternatives. One reason for such variation can be attributed to the similarity of elements, which means feasibility and novelty are evaluated upon alternatives whereas comprehensiveness, persuasiveness, and insightfulness are evaluated upon tradeoffs.

The Variance Inflation Factor (VIF) values for these multiple regression models are 2.300, which is smaller than 5, indicating that these models do not have multicollinearity problems (O'Brien, 2007). That is, individual predictors in the regression model, meaning feasibility of design alternatives and comprehensiveness of tradeoffs, are not redundant or highly correlated. Their coefficient values provide somewhat precise estimate of their effects on the three aspects of creativity.

Furthermore, we tested whether there is any moderation effect or interaction effect of feasibility of design alternatives and comprehensiveness of tradeoffs by centering these two variables. No significant effect was detected.

Regression analysis on the second data set also suggests that feasibility of design alternatives and comprehensiveness of tradeoffs are two critical properties of design rationale to enhance creativity in software design. The second data set does not include rating scores on design rationale of students who did not participate in the surveys. Independent variables that entered into the three regression models were slightly different from those in the models shown in Table 1. Table 2 summarizes the models for predicting the three aspects of creativity on the second data set. The model predicting novelty of alternatives is Novelty = 0.554 * Feasibility +0.228 * Comprehensiveness, $F(2, 43) = 94.394$, $p < .001$, $R^2 = .832$. The model for predicting persuasiveness of tradeoffs is Persuasiveness = 0.295 * Feasibility +0.664 * Comprehensiveness, $F(2, 38) = 126.41$, $p < .001$, $R^2 = .869$. The model for predicting insightfulness of tradeoffs is Insightfulness = 0.297 * Decision +0.746 * Comprehensiveness, $F(2, 38) = 122.94$, $p < .001$, $R^2 = .866$. The main difference between results generated from the two data sets is that the independent

Table 2. Relationship Between Rationale Quality and Creativity on the Second Data Set ($N = 46$).

Model	Quality of DR (IV 1)	Coefficient 1	Quality of DR (IV 2)	Coefficient 2	Creativity (DV)
1	Feasibility of Alternatives	0.554***	Comprehensiveness of Tradeoffs	0.228** ($p = .002$)	Novelty of Alternatives
2	Feasibility of Alternatives	0.295* ($p = .013$)	Comprehensiveness of Tradeoffs	0.664***	Persuasiveness of Tradeoffs
3	Decision	0.297* ($p = .044$)	Comprehensiveness of Tradeoffs	0.746***	Insightfulness of Tradeoffs

Note: Significance level: *** $p < .001$, ** $p < .01$, * $p < .05$

variable feasibility of alternatives is replaced by decision optimization in the model predicting insightfulness of tradeoffs. However, the significance of the estimated effect from decision is only 0.044, which is not significant enough as compared to more conservative alpha value rather than the default 0.5.

Similarly, neither a multicollinearity problem nor interaction effect has been discovered. The values of VIF for each model are 2.588, 2.588 and 2.902, respectively.

The common structure revealed by both data sets was the positive correlation between comprehensiveness of tradeoffs and creativity. Other than analytical and critical thinking ability, comprehensiveness can be accomplished from knowledge and expertise in related areas. To analyze whether their prior knowledge in software design affected the comprehensiveness of their articulation of tradeoffs, we collected 14 participants' background information in our last survey. According to the results of a nonparametric test, no significant difference was found between students who had prior experience in object-oriented design before the advanced course (mean of comprehensiveness = 1.71) and those who did not (mean of comprehensiveness = 1.92), nor between students who had built software in their spare time during the previous year (mean of comprehensiveness = 1.30) and those who had not (mean of comprehensiveness = 2.13).

With respect to the third research question, we conducted regression analysis on variables of rationale quality, creativity, and perceived creative processes. We did not find any significant mediation effect of the perceived creative processes upon the quality of design rationale and the creativity in design, nor did we find any significant relationship between the quality of rationale and creative processes, or between creative processes and creativity.

RQ4: How Will Sharing Design Rationale Across Groups Influence Group's Creative Design Processes?

To investigate the fourth research question about the impacts of sharing rationale across groups on creative processes, we collected participants' ratings on perceived creative processes by revisiting their prior design rationale through these items in our second and third surveys (The first survey was excluded because students had not yet started working in teams at that time):

1. The pros and cons articulated for our prior labs or projects evoked more design alternatives of my team.

2. The pros and cons articulated for our prior labs or projects helped my current team members and me pick the best design solution to our current lab.

The first question concerns divergent thinking in creative processes, while the second one is about convergent thinking. Both of them were rated on 9-point Likert scale. However, since sharing design rationale across groups was neither an imperative for all students nor controlled for in different groups, we also asked students in the surveys whether they shared their previous design rationale with their current team members.

Twenty-six responses to these questions in total were collected: half of them (n = 13) did share their prior design rationale with the current group members, while the other half (n = 13) did not. Table 3 presents the descriptive statistics of participants' ratings on their current groups' divergent thinking process and convergent thinking process. According to the mean values of ratings (in the column "Mean"), whether or not they shared their previous design rationale across groups, participants on average felt that they benefited from the rationale of their previous design activities (mean of perceived creative processes > 5). Tables 4 and 5 show crosstabs for each survey question. They also suggest that most of participants thought sharing design rationale across groups was helpful.

We further examined whether sharing prior rationale affected the creative processes of the group. Results indicate that it affected and only affected groups' convergent thinking and decision making. Because neither set of 13 cases had normal distribution, we compared the perceived creative processes between groups who shared their rationale across groups and those who did not share across groups by conducting nonparametric t-test. According to the results of Mann-Whitney testing, sharing previous design rationale did not have significant effect on a group's divergent thinking (Asymp. Sig. = .202) but did have significant effect on a group's convergent thinking and decision making (Asymp. Sig. = .039). These results suggest that speculating and communicating with group members on rationale of a related design might assist a group's convergent thinking and decision making. Besides effect on the groups' perceived creative processes, we examined whether such intergroup sharing also affected the quality of rationale and the creativity of the new design. However, no significant difference was found between participants who shared rationale across groups and those who did not. This may indicate that introducing other groups' design rationale would boost their confidence in their consensus but did not make a big difference in real performance. These results will be explained and discussed more in the next section.

Table 3. Comparison of Perceived Creative Processes Between Groups with Intergroup Sharing of Rationale (n = 13) and Groups Without Intergroup Sharing of Rationale (n = 13).

Perceived Creative Processes	Intergroup Sharing of Rationale	*n*	Mean	Std. Deviation
The pros and cons articulated for our prior labs or projects evoked more design alternatives of my team.	0 (not share)	13	5.31	1.49
	1 (shared)	13	6.08	1.04
The pros and cons articulated for our prior labs or projects helped my current team members and me pick the best design solution to our current lab.	0 (not share)	13	5.31	1.55
	1 (shared)	13	6.46	1.13

Table 4. Cross Tabulation of Intergroup Sharing of Rationale*Perceived Convergent Thinking.

Count		The pros and cons articulated for our prior labs or projects helped my current team members and me pick the best design solution to our current lab.					Total
		Rating=1	Rating=5	Rating=6	Rating=7	Rating=8	
Intergroup Sharing of Rationale	0 (not share)	1	7	2	3	0	13
	1 (shared)	0	3	4	3	3	13
Total		1	10	6	6	3	26

Table 5. Cross Tabulation of Intergroup Sharing of Rationale*Perceived Divergent Thinking.

Count		The pros and cons articulated for our prior labs or projects evoked more design alternatives of my team.					Total
		Rating=1	Rating=5	Rating=6	Rating=7	Rating=8	
Intergroup Sharing of Rationale	0 (not share)	1	6	4	2	0	13
	1 (shared)	0	5	3	4	1	13
Total		1	11	7	6	1	26

DISCUSSION

Our hypothesis that rationale and creativity in software design are mutually facilitative and potentially integrable is supported by our classroom study results. Moreover, the feasibility of design alternatives and comprehensiveness of tradeoffs are found to be the most critical properties of rationale quality that are positively correlated with novelty of design alternatives, persuasiveness, and insightfulness of tradeoffs. These two properties of design rationale quality involve critical thinking and evaluation ability in different ways. Despite its limitations, our study opens up opportunities to further investigate how to take advantage of design rationale to enhance the effectiveness and creativity of software design.

Implications

Quality of Design Rationale Facilitates Design Creativity

Our study indicates the positive correlation between rationale and creativity in software design. Although we cannot assert a causal relationship between rationale quality and creativity through our regression analysis, all of the aspects of rationale quality we measured are positive predictors for design creativity. Thus it is plausible to foster design creativity by enhancing the quality of design rationale. The judges might tend to assign similar scores to rationale quality and creativity of each document based on their overall impression of the document. This

consistency of individual's judgment can be mitigated by introducing more judges and asking each of them to either assess rationale quality or creativity.

Feasibility and Comprehensiveness of Rationale Enhances Design Creativity

Given the confirmation on their integrative potential, characteristics of rationale quality were examined to help us contemplate on why design rationale can promote creativity and how we can support creativity in software design by design rationale. Although analysis on the two data sets with different sizes ideally would have shown the same pattern, the results still indicate two critical properties of design rationale that facilitate design creativity: feasibility of design alternatives and comprehensiveness of arguments. By comparing the properties of rationale quality that entered into our final regression models with those that did not, it is not hard to discern that the ones with weak predictability to creativity (i.e., problem identification, relevance of design alternatives and clarity of articulation) are low-level requirements for designers' capacity.

Feasibility of design alternatives may manifest a higher level of designers' capability and the internal evaluation of designers and their groups, which involves their critically selecting the ideas that can be externalized and recorded in their design rationale. Constraints over design space are not always a negative within the creative process; rather constraints are continually applied in good design (Singley & Carroll, 1996). They pose finites to the space, directing design turned into product. Additionally, creativity is not just about wild thinking; it requires action and implementation (West, 2003). One can hardly operationalize alternatives far beyond one's design knowledge. In this sense, it may also be reasonable to attribute feasibility as one aspect of creativity. Furthermore, creativity, especially divergent thinking, is often mistakenly simplified to represent the number of ideas generated. However, creativity is not only about quantity, but more about quality (Farooq, 2008). Emphasizing the feasibility of design alternatives may filter out some spontaneous thoughts, but it can ensure the design is doable. Aligned with the same concern, the grading rubrics provided to students did not require any specific number of design alternatives so that students would not be motivated to generate some invaluable options. Moreover, in general, the assessing feasibility may be biased by the judges' expertise due to the possible gap between judges' and designers' design knowledge, particularly when the design proposals may be executable for designers but beyond judges' skills. However, in our case the judges are teaching assistants who have privileged experience in the course content and design skills. Thus judgment on feasibility in our study should be considered fair and reliable.

Another aspect of rationale quality—comprehensiveness of tradeoffs—consistently contributes as a significant predicator in the six regression models shown in Tables 1 and 2. Comprehensiveness and correctness decide whether critical reasoning in rationale has positive or negative effect on design (Singley & Carroll, 1996). With comprehensive evaluation, designers will not be confined by the downsides of design options but may be able to create new options that can augment the upsides and mitigate the downsides. Comprehensiveness is neither complexity nor detailing every relevant issue. Nevertheless, it is necessary to capture and enumerate each critical issue in design alternatives in order to achieve comprehensiveness. Considering our study context, effects from comprehensiveness on creativity may also likely come from participants' efforts in their work required by achieving comprehensiveness. Even if

they are capable of envisioning all of the critical upsides and downsides, designers are normally not motivated to think thoroughly the entire evaluation space and record all considerations. In general, people generally do not make sophisticated analyses to make rational decisions. They would rather just pick one solution candidate that works.

Comprehensiveness also requires adequate knowledge to justify design options. With limited knowledge or expertise, designers may foresee only part of possible consequences, or they may exert all of their efforts on trivial problems but lose sight of the whole picture. The facilitative relationship between comprehensiveness of tradeoffs and creativity may motivate designers to take a more positive attitude toward constructing their design rationale, rather than negatively consider it as overhead, like any other documentation. Furthermore, tradeoffs encompass both pros and cons. Comprehensiveness does not specify a certain portion or weight for each part; even tradeoffs without many cons can be comprehensive. Thus it may provide us more insights to further examine how comprehensiveness of argumentation influences creativity by decomposing argumentation into pros and cons.

Intergroup Rationale Sharing Assists Group's Convergent Thinking

Our analysis on intergroup sharing of design rationale indicates that sharing prior design rationale other than reusing it across groups may facilitate convergent thinking. There are always motivational obstacles that inhibit information flow across organizational boundaries and difficulty in making sense of unfamiliar contexts. Designers may be even more reluctant to revisit their previous or other designers' rationale documents than to create their own for current practices due to the cost of making sense of those documentations. Groups are often not quite motivated to share information with or incorporate information from other groups unless they have specific needs. In our study, the sharing rationale across groups may be less inhibited by those factors. Students maintain a consistent context because they all know the tasks of each lab. Prior design rationale is reusable because posterior lab assignments are built on the design of anterior ones. Moreover, the rotation of group members ensures that each member in a group has adequate knowledge about the rationale created by his or her prior groups. One incentive to revisit previous design is that students were aware of something wrong in their prior design. By explaining their previous design rationale to their current group members, students might have developed shared understanding and common ground, which assisted with their decision making. However, they did not perceive much difference in the process of coming up more alternatives, whether or not they shared their prior rationale. This may have resulted from the superiority of the instructors' solutions to prior lab assignments. In other words, students may only have applied their previous design rationale to prune poor design options to protect themselves from making the same mistakes. They relied more on instructors' previous designs to generate options for current problems. They judged their previous design based on instructors' solutions. As long as they did not discern any significant difference, they will stop exploring other design alternatives. Such satisficing tendencies (Ball, Maskill, & Ormerod, 1998; Ormerod, Mariani, Ball, & Lambell, 1999) restricted the impact of intergroup sharing of design rationale on groups' divergent thinking. For example, more than one student believed that he or she used the same approach for the next lab assignment as the one for the previous lab because their prior design fit instructors' solution well. Therefore, the motivation for intergroup sharing determines how

students reflect on and use their previous design rationale, which is part of their creative design processes. By further investigating the various motivations, we could more precisely understand the effects of sharing design rationale across groups on group creativity.

Limitations

Our findings are constrained by the characteristic of the task. We did not deploy a direct measurement on the design product (i.e., the code), which arises from the concerns that the lab assignments in our study were relatively close-ended problem solving. In order to obtain a more precise assessment on design creativity, we plan to design more open-ended tasks.

Moreover, our results are limited by our measurement of rationale quality and creativity. Each judge in our study rated both rationale quality and creativity of every rationale document. Thus the positive correlation between rationale quality and creativity may result from the inherent consistency of each individual judge. In the future, we may employ more judges to assess rationale quality and design creativity separately, with each judge rating only one part. This can also balance the individual differences among judges. Alternatively, we can ask judges to qualitatively evaluate the relationship between the design rationales and creativity on the basis of their informed interpretation of rationale quality and creativity. To improve the interrater reliability, we can decompose our assessment criteria and facilitate further discussion on them with all judges.

Additionally, our analysis is confined by the class size. For instance, the required number of cases for stepwise multiple regression should be 40 times the number of independent variables, as recommended by Tabachnick and Fidell (1996). One way to approach a more robust conclusion is to recruit more participants.

Further Issues

Since our evaluation criteria on rationale quality are not exhaustive, feasibility of design alternatives and comprehensiveness of tradeoffs may not be the only quality facets related to creativity. Other properties we assessed in terms of rationale quality may also predict facets of creativity other than the three (i.e., novelty, persuasiveness, and insightfulness) measured in our study. Nonetheless, the positive correlation between rationale quality and creativity demonstrated in our empirical study connotes rationale articulation as a way to enhance creativity in software development. This certainly does not imply that documenting design rationale with any approach will necessarily lead to creativity enhancement, but rather inspires the dedication to investigate how to appropriate design rationale and what qualities of rationale should be amplified to support creativity in software development. The rationale qualities facilitating creativity discovered in our study will guide the effort to further elucidate the underpinning reasons why these qualities are critical to enhance design creativity.

The ways that rationale and creativity influence each other need further investigation in collaborative settings. Software design is a complex and ill-defined problem-solving process, which has increasingly demanded collaboration among individuals as the scale of projects grows. To achieve creativity in such situations, it is desired to keep track of the development process. Furthermore, mere individual intellects are hardly sufficient to attain creative design artifacts. Instead, the collective accomplishment will arise from the interaction between and

among group members. The role of design rationale in these scenarios may not only involve facilitating individuals' analytic thinking but rather influencing the communication and cooperation processes when rationale is constructed and captured by collective effort. Therefore, it is intriguing and promising to further explore how design rationale articulation affects creative design processes of the group.

CONCLUSION AND FUTURE WORK

When designers think about rationale, they often tend to believe it suffocates design and undermines the possibility of creativity. In this paper, our study provides empirical evidence to argue that the relationship between rationale and creativity is more than contrast. Instead, rationales and rationale practices can be adapted to enhance creativity in design. Furthermore, based on our assessment of rationale quality and creativity, the feasibility of design alternatives and comprehensiveness of argumentation or tradeoffs have significant positive effects on the novelty of design alternatives, the persuasiveness, and the insightfulness of argumentation. These effects may derive from designers' internal evaluation and critical thinking on design alternatives. They are not bounded by the particular domain in our study (i.e., software design); instead, reasoning and critical thinking can have such effects in any other domain in which they are involved and creativity can happen. Therefore, we can expect that rationale and creativity are mutually facilitative in other domains beyond software engineering and design.

Similarly, our assessment criteria on rationale quality may also be adapted to real-world contexts outside of classrooms. Previous work allows evaluating rationale in terms of their usability by analyzing cognitive costs of different notational forms or in terms of their usefulness by observing their use and narrating anecdotes. Our rubrics provide a quantitative approach to evaluate the quality of design rationale, emphasizing the quality of critical thinking that is related to design creativity. It can be developed to assess real design practices by integrating concerns with organizational factors as well as management issues.

Yet to explain exactly how rationale facilitates creativity and why these two properties are strong predicators, we have to investigate their effects on the creative processes by refining survey questions and collecting more qualitative data. For comprehensiveness, we may also need to look at tradeoffs from pros and cons separately.

Our observation on sharing rationale across groups stimulates us to explore further the various motivations for sharing design rationale and design reuse to understand when to facilitate intergroup sharing. This is worth investigation because design rationale is usually expected to convey the reasoning and decision process of other designers.

In the even longer term, understanding the benefits of design rationale for creativity in software development will inform how to build tools to support creative design.

ENDNOTE

1. This was a workshop on creativity and rationale in software design sponsored by NSF CreativeIT program. It was held at University Park, PA in June, 2008. John M. Carroll wrote a manifesto, "The Essential Tension of Creativity and Rationale in Software Design," for this workshop.

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APPENDIX

Evaluation Criteria

Quality of Design Rationale (1 = *very poor*, 5 = *very good*)

Toughest Design Problem Identification:
Does the statement of toughest design problem capture a critical issue of this lab?

Relevance of alternatives:
Can the design alternatives solve the problem stated?

Feasibility of alternatives:
Can the design alternatives be implemented by using the technique taught in class?

Comprehensiveness of tradeoffs (pros and cons):
Do the tradeoffs reveal main concerns about each design alternative?

Decision:
Is the design alternative selected the optimal solution?

Clarity of articulation:
Can the report be well understood?

Creativity of Design

Novelty of design alternatives:
Are the design alternatives novel?

Persuasiveness of tradeoffs:
Are the tradeoffs persuasive?

Insightfulness of tradeoffs:
Do the tradeoffs provide insightful justification of design alternatives?