Requirements Fixation

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ABSTRACT

Background: There is a broad consensus that understanding system desiderata (requirements) and design creativity are both important for software engineering success. However, little research has addressed the relationship between design creativity and the way requirements are framed or presented. *Aim:* This paper aims to investigate the possibility that the way desiderata are framed or presented can affect design creativity. *Method*: 42 participants took part in a randomized control trial where one group received desiderata framed as "requirements" while the other received desiderata framed as "ideas". Participants produced design concepts which were judged for originality. *Results*: Participants who received requirements framing produced significantly less original designs than participants who received ideas framing (Mann-Whitney U=116.5, p=0.004). *Conclusion:* framing desiderata as "requirements" may cause *requirements fixation* where designers' preoccupation with satisfying explicit requirements inhibits their creativity.

Categories and Subject Descriptors

D.2.1, D.2.10 [**Software Engineering**]: Requirements/ Specifications, Design

General Terms

Documentation, Design, Experimentation, Human Factors

Keywords

Design Creativity, Requirements, Cognitive Bias, Randomized Controlled Trial

1. INTRODUCTION

It is widely accepted in the software engineering (SE) research community that understanding system requirements is critical to designing good systems (cf. [16, 20, 32, 81, 85, 89, 99, 100]). While some disagree as to whether requirements should be understood more upfront (e.g. [38, 44]) or as development progresses (e.g. [5, 14]) most agree that requirements are important sooner or later. Practitioners similarly treat requirements-understanding as crucial to system success especially in outsourcing and tendering contracts [11]. The dangers of getting requirements wrong or failing to account for requirements changes are widely recognized [15, 41, 64, 103]. Requirements Engineering (RE) research has consequently investigated techniques for eliciting, analyzing, modeling and communicating requirements.

ICSE'14, May 31 – June 7, 2014, Hyderabad, India

How a situation is *framed*, however, can have powerful effects on the cognition and performance of human participants (see below). Some (e.g. [78]) have suggested that framing the context of a software development project in terms of requirements may deleteriously affect design creativity. Specifically, misperceiving all 'requirements' as compulsory may interfere with design space exploration. Yet, little research has empirically investigated the effects of presenting desiderata as "requirements" on design creativity. We therefore propose the following research question.

> ***Research Question:*** *Does framing desiderata as "requirements" negatively affect creativity in design concept generation?*

Here, a *desideratum* is "something for which a desire or longing is felt; something wanting and required or desired" [66]. *Requirement*, meanwhile, has been defined in several ways including "a statement that identifies a capability or function that is needed by a system in order to satisfy its customer's needs" [4] and "a property that must be exhibited in order to solve some problem in the real world" [9]. Others emphasize that requirements state "what a system is supposed to do, as opposed to how it should do it" [102]. Here, *framing* therefore refers to how the desiderata are presented or communicated; e.g., a list of "the system shall..." requirements [40]; a backlog of user stories [87]; a set of use case narratives [23]. In other words, when a desideratum is presented as mandatory, it is being framed as a requirement. Meanwhile, *design concept generation* refers to informally specifying one or more ideas for a software artifact. Designers often use sketching [69], storyboarding [95] or other informal modeling techniques to specify design concepts.

We theorize that framing desiderata as "requirements" will lead to less creative designs. Specifically, we suspect that the high importance and confidence connoted by the term *requirement* shuts down designer's creative processes by promoting the view that the problem is well-understood and already largely solved.

The paper therefore proceeds by reviewing existing literature on fixation and requirements engineering (§2). Next we propose the concept "requirements fixation" and describe the methodology (§3) and results (§4) of a laboratory study of this concept. Section 5 discusses the interpretation and implications of the findings and the Section 6 concludes the paper with a summary of its contributions and suggestions for future research.

2. LITERATURE REVIEW

2.1 Fixation

Cognitive biases are systematic deviations from optimal reasoning [80, 91] or psychological phenomena that “prejudice decision quality in a significant number of decisions for a significant number of people” [3]. Many cognitive biases have been discovered – Arnott alone reviews 37 [3]. Previous research has investigated the role of myriad cognitive biases in software engineering generally (e.g. [67, 80, 90]) and requirements engineering specifically (e.g. [12]). The current study is concerned primarily with two biases – *fixation* and *framing effects*.

Fixation was originally proposed by Freud in reference to unusual sexual traits; however, its meaning has since broadened to refer to the tendency to “disproportionately focus on one aspect of an event, object, or situation, especially self-imposed or imaginary obstacles” [80]. People can fixate on myriad objects and properties; e.g., the color of a car, the presence of a spider, the placement of a button. Fixating on one aspect of something usually implies marginalizing other aspects; e.g., fixating on a software system’s speed while ignoring its aesthetics, or vice versa.

Jansson and Smith proposed the concept *design fixation* – “a blind adherence to a set of ideas or concepts limiting the output of conceptual design” [42]. In a series of experiments on design fixation, participants were asked to design a bicycle rack for a car, a measuring cup for the blind, and a spill-proof coffee cup. In each case, participants were divided into two groups and the treatment group was given a flawed example design. Treatment groups consistently produced more designs that mimicked negative aspects of the flawed example design. For instance, in the measuring cup study, the treatment group “generated more non-infinitely variable designs than the control group, more designs without overflow devices, and more overall designs similar to the example” [42].

Numerous replications, extensions and variations on Jansson and Smith’s methodology have since been published, with myriad results. For instance, propensity for fixation varies by domain; e.g., mechanical engineers fixate more than industrial designers [70-73]. When designers are given good, rather than intentionally flawed, examples, they still fixate on the example but they produce higher-quality designs than designers without examples. [49]. Presenting designers with common ideas (or examples) produces more fixation than than unusual examples [68]. Some evidence suggests that fixation can be mitigated by “defixating” instructions [21], i.e., instructions to avoid problematic features of given examples. Some evidence suggests that physical prototyping reduces design fixation [101]. Meanwhile in software engineering, some have suggested that inconsistency in software specifications may reduce premature commitment [65].

Moreover, one would expect (fixated) treatment groups to produce fewer designs than control groups. However, no evidence of such a relationship has been found [42, 49, 70-73]. It is not clear whether this results from the nature of fixation and creativity or from the time limits imposed on participants in these studies.

In summary, numerous studies have found that designers fixate on given examples in laboratory settings. The relationship between fixation and solution quality is moderated by example quality. The relationship between fixation and creativity is moderated by the domain (e.g., mechanical engineering), task (e.g. physical prototyping) and the *framing* of the examples (e.g. de-fixating instructions). This last point highlights the relationship between fixation and framing.

2.2 Framing Effects

Another cognitive bias, related to fixation, is the *framing effect.* The “framing effect is the tendency to give different responses to problems that have surface dissimilarities but that are really formally identical” [91]. For example, in one experiment, participants were asked to choose between two treatments for a hypothetical disease – Treatment A would save 200 of 600 people; Treatment B had a 1 in 3 chance of saving everyone and and 2 in 3 chance of saving no one. When participants were asked to choose between 400 people definitely dying or a 1 in 3 chance that no one will die, most chose the latter. However, when participants were asked to choose between definitely saving 200 people or a 1 in 3 chance of saving everyone, most chose the former [96]. Here, the difference in responses is entirely attributable to the way the question is presented (or *framed*) rather than the underlying structure of the treatments.

The framing effect is extremely robust [7, 19, 47, 97]; i.e., it applies to many people across diverse circumstances. Levin et al. [47] identified three types of things framed in existing studies – individual attributes, goal statements and risk profiles (as in the hypothetical disease, above). Of course, framing effects have been leveraged in marketing and advertising for many years [46], which explains why notebook computers are described as “1.7cm thin”. However, framing effects are somewhat mitigated by task involvement [51, 83].

When researchers (e.g. [21]) investigate fixation by giving participants different instructions, the independent variable may be considered task framing and the results (fixation) may be considered a kind of framing effect. Of course, fixation is not inherently a framing effect – people can become fixated without intervention. However, most existing studies of fixation leverage framing effects. Consequently, the primary conclusion of design fixation research may be reconceptualized from *designers fixate on given examples* to *task framing causes fixation.*

In software engineering however, developers are more often asked to design a system based on some sort of requirements specification. This raises the question, *can the framing of a requirements specification lead to fixation and reduce creativity?*

2.3 Requirements, Design and Creativity

Like Software Engineering, Requirements Engineering (RE) simultaneously refers to a collection of activities and the academic field that studies those activities. While no single definition of requirements engineering is widely accepted, the activities in question include understanding, specifying, documenting, communicating and modifying problems, needs, wants and other desiderata [15, 18]. RE may also focus on goals [2, 28, 98], users [57, 93], agents [10] and non-functional properties [22, 37, 60]. RE is also concerned with analyzing and predicting numerous properties of desiderata, including stability [13, 40].

RE is often portrayed as relatively independent from designing and implementing software systems. Many authors (e.g. [4, 102]) emphasize that RE primarily concerns determining what the software should do rather than how it should do it. The interdisciplinary design literature, in contrast, emphasizes that problem framing and solution generation are fundamentally the same cognitive process [27, 86]. Specifically, empirical studies of expert designers reveal that designers rapidly oscillate between their understanding of the context and ideas for design candidates, simultaneously revising both – a process sometimes called *coevolution* [30, 50]. Some research has also explored coevolution in software engineering [74, 77, 79].

Coevolution is closely related to creativity [36], which is increasingly recognized as important within RE. Some now argue that RE is an inherently creative act [52-55]. For example, Maiden et al. argue that “requirements are the key abstraction that encapsulates the results of creative thinking about the vision of an innovative product” [55] and that RE processes may be improved by integrating creativity techniques [53]. Producing truly innovative products entails inventing requirements no client or user may think of [82]. Field research clearly suggests that RE is creative and opportunistic in practice [62]. Four trends are driving this need to incorporate creativity into requirements processes – 1) the strategic importance of creativity for competitive advantage; 2) the increasing diversity of devices and applications; 3) the increasing acceptance of coevolution in (particularly Agile) systems development methods; 4) the increasing interest in creativity among requirements practitioners [54].

Recent research on requirements creativity straddle the gulf between the two design paradigms [29, 31, 76]. In the rational paradigm (which dominates engineering), clients have requirements, analysts elicit those requirements and developers search for solutions that satisfy requirements [11]. Contrastingly, in the alternative paradigm (which dominates product and industrial design) designers are faced with problematic situations characterized by goal disagreement [17] and few definitive requirements [78]; designers simultaneously refine their understandings of the context and solution space, often exploring the context *by* generating design concepts [74]. The rational paradigm traditionally downplays the importance of creativity since design is presented as heuristic search of a known, constrained solution space [88]. Meanwhile the alternative paradigm traditionally emphasizes the importance of creativity for good design.

Moreover, creativity itself is the focus of much research in myriad fields including psychology, sociology, management and education. While a comprehensive review is beyond the scope of this paper, several points warrant discussion. First, no single definition of creativity is widely accepted; however, there is broad consensus that creativity is a cognitive process that produces novel and useful ideas [59]. Some distinguish between creativity from different perspectives – the individual designer’s (p-creativity), the specific design context’s (s-creativity) or society’s (h-creativity) [6, 94]. Creativity depends on cognitive skills, risk tolerance, domain specific knowledge and many situational factors [1]. It also relates to social context in that it involves deviating from social norms and structures [26]. Creativity is related to but separate from intelligence [61, 92].

Creativity is often linked to *divergent thinking* [39], i.e., exploring many possible solutions to a problem rather than deriving a single correct answer. However, divergent thinking is not equivalent to creativity as the former entails seeing many possibilities but not necessarily creating anything novel or useful [84]. Rather, creativity involves generating many ideas, some better than others, and then effectively identifying the best.

3. RESEARCH METHODOLOGY

This section describes an exploratory experiment to investigate the relationship between desiderata framing (the independent variable) and the originality of design concepts (the dependent variable). Briefly, participants were given a list of desiderata framed as either “requirements” or “ideas” and asked to generate design concepts. We then rated the design concepts for originality. If one group produced substantially more original designs, it would suggest that desiderata framing affects creativity.

3.1 Theorizing Requirements Fixation

During a previous study, the second author observed a team developing a mobile application. The client provided a quite rudimentary and generally poor design concept with instructions to essentially ‘build something like this’. Rather than question or try to improve this simple specification, the developers appeared to take it for granted and began coding. After an intervention, the team recognized the design flaws, threw away the specification and designed the system from scratch. The client subsequently felt that the new design was a major improvement.

This led us to theorize that, in some cases, software developers are sensitive to *requirements fixation*: the tendency to disproportionately focus on desiderata that are explicitly framed as requirements. Symptoms of requirements fixation may include:

- failing to question dubious desiderata
- perceiving desiderata as having equal (high) importance
- perceiving all desiderata as having equal (high) confidence
- failing to consider the relationship between desiderata and overall goals
- failing to notice conflicting desiderata
- failing to notice desiderata ambiguity
- failing to consider implicit or non-functional desiderata

Like design fixation, requirements fixation is clearly too complex to evaluate holistically in a single study. We therefore begin by examining the relationship between the framing of desiderata and the originality of design concepts using an experimental design analogous to previous design fixation experiments (§2.1).

3.2 Hypothesis

We hypothesize that design concept originality will be lower when desiderata are framed as “requirements” than when they are framed as “ideas”. When desiderata are framed as “requirements”, we expect participants to perceive the desiderata as complete, certain or fixed, triggering fixation and reducing creativity. In contrast, when desiderata are framed as “ideas” we expect participants to perceive the desiderata as incomplete, uncertain or flexible. This conceptualization should trigger more creative thinking, which should lead to more innovative, creative designs. Consequently, our hypothesis is as follows.

> ***Hypothesis H_0:*** *Participants who receive desiderata framed as “requirements” will produce neither more nor less creative design concepts than participants who receive desiderata framed as “ideas”.*

> ***Hypothesis H_1:*** *Participants who receive desiderata framed as “requirements” will produce less creative design concepts than participants who receive desiderata framed as “ideas”.*

3.3 Participants

Participation was solicited from post-graduate students enrolled in management and engineering programs at the authors’ university using relevant student mailing lists. A convenience sample of 42 participants was selected – 19 female and 23 male, with a mean age of 25 years (standard deviation 6.067). All participants had at least 1 year of professional design experience, with 14 coming from a software engineering background. None of the participants had design experience in the particular field of the task, i.e., mobile applications. Participants received no financial compensation but a complementary lunch was provided.

3.4 Experimental design

A between-subjects randomized controlled trial was chosen for this study. Participants were randomly assigned to one of two equally-sized groups – Group A and Group B. Group A and Group B completed the study in separate but very similar rooms, each with a single invigilator. The invigilator distributed materials, read the instructions and collected the completed templates. The invigilator did not answer any questions.

The directions differed between the groups in exactly two ways. First, Group A's opening paragraph read:

> "For this study your task is to develop one or more design concepts for a mobile application to encourage healthy living. A design concept is a high-level description of a system. To help, an analyst has conducted several focus groups around campus and produced the following *requirements specification.*" (italics added)

While Group B's opening paragraph read:

> "For this study your task is to develop one or more design concepts for a mobile application to encourage healthy living. A design concept is a high-level description of a system. To help, an analyst has conducted several focus groups around campus and produced the following *list of ideas.*" (italics added)

Neither "ideas" nor "requirements" were defined so as to retain participants' natural preconceptions and biases. These directions were followed by a list of 24 desiderata for the app. Both groups received the same desiderata in the same order. However, Group A's desiderata began with "the system shall" (consistent with IEEE-830 [40]) while Group B's desiderata began with "the system might". No other differences between the two groups were introduced.

The desiderata themselves were written by the authors based on features of existing health-related apps. The idea was to create a realistically imperfect spec (cf. [4]) – the kind of jumble of ideas that might be written by unsophisticated client or a programmer with little RE training, rather than the polished work of an expert requirements analyst. In other words, we tried to make a document representative of what we have observed in previous field work and professional practice. The desiderata (minus the "the system shall / might" prefix) were as follows.

- play music
- reduce stress
- recommend activities
- recommend diet foods
- measure calorie intake
- facilitate diet planning
- analyze sleeping habits
- users share their experiences
- allow the user to plan workouts
- be user friendly and easy to use
- be technically stable and not crash
- track BMR (Basal Metabolic Rate)
- track what the user eats and drinks
- be compatible with iOS and Android
- count calories burned during workouts
- help the user stick to planned workouts
- recommend recipes based on user goals
- share user accomplishments on Facebook
- suggest 'power foods' based on my BMR
- connect the user to a doctor in an emergency
- track speed and distance for running, swimming, etc.
- provide instruction for diverse exercises and activities
- retain workout history and provide performance analysis
- recommend specific workouts at varying levels of difficulty

In addition to the desiderata, participants were given a conceptual design template comprising several sheets of paper with blank mobile-screen-sized boxes in landscape and portrait views and adjacent space for explanations (Figures 1 and 2). Participants could use as many templates as needed.

Participants had 60 minutes in which to complete their designs. The invigilator then distributed a post-task questionnaire which recorded demographic and contact information. All questions were optional. The post-task questionnaire also included a manipulation check where participants were asked to indicate the importance of the desiderata in guiding their conceptual designs on a five-point scale.

3.5 Grading

Two expert judges (the first and third authors) independently graded the conceptual designs. Prior to grading, the conceptual designs were anonymized, combined into a single set and randomly shuffled such that the judges knew neither the participant nor the group to which each design belonged. To keep the evaluation as simple (and robust) as possible, there was no complicated rubric for evaluating designs; rather, judges used a simple five-point scale where a 1 indicates low originality and a 5 indicates high originality. We felt that a more granular scale would lead to overprecision [58]. Here, originality refers to creativity from the perspective of society, or h-creativity [6].

The judges discussed and marked the first 3 designs together to establish a shared baseline. For example, in Figures 1 (from the "ideas" group) and 2 (from the "requirements" group) we can see how two different participants implemented diet tracking - one using a simple written description while the other attempts to quantify calories. The week-level overview (Figure 1) and ability to share pictures of food (Figure 2) were considered especially innovative. Figure 2 is notably more complex, feature-rich and messy while Figure 1 is simpler and cleaner but with fewer features.

The judges then marked the remaining designs separately (in different rooms). As these ratings are subjective judgments, reliability may be examined by calculating inter-rater agreement. The judges agreed on 34 of the 42 conceptual designs. Using Cohen's Kappa [24], this gives an inter-rater agreement of 0.67, which represents "substantial agreement" and therefore reasonable reliability [45]. Disagreements were resolved by a third expert judge (the second author) to create the grade data set used in the analysis below.

4. RESULTS AND ANALYSIS

To test Hypothesis H_1, we need to compare the distributions of originality grades (Table 1). Ideally we would test Hypothesis H_1 with an efficient, parametric test such as an independent samples t-test or (equivalently) a one-way analysis of variance. However, these tests assume a normal distribution and homogeneity of variance. Visual inspection of Figure 3 suggests that *Grades* may not satisfy these assumptions. Homogeneity of variance may be analyzed using Levene's test, the Brown-Forsythe test and Levene's non-parametric test [25]. As none of the three tests rejected the null hypothesis (Table 2) we assume that *grades* meets the homogeneity of variance assumption. However, analysis using the Shapiro-Wilk test confirms we cannot safely assume that *Grades* is normally distributed ($p < 0.001$ for Group A; $p = 0.003$ for Group B).

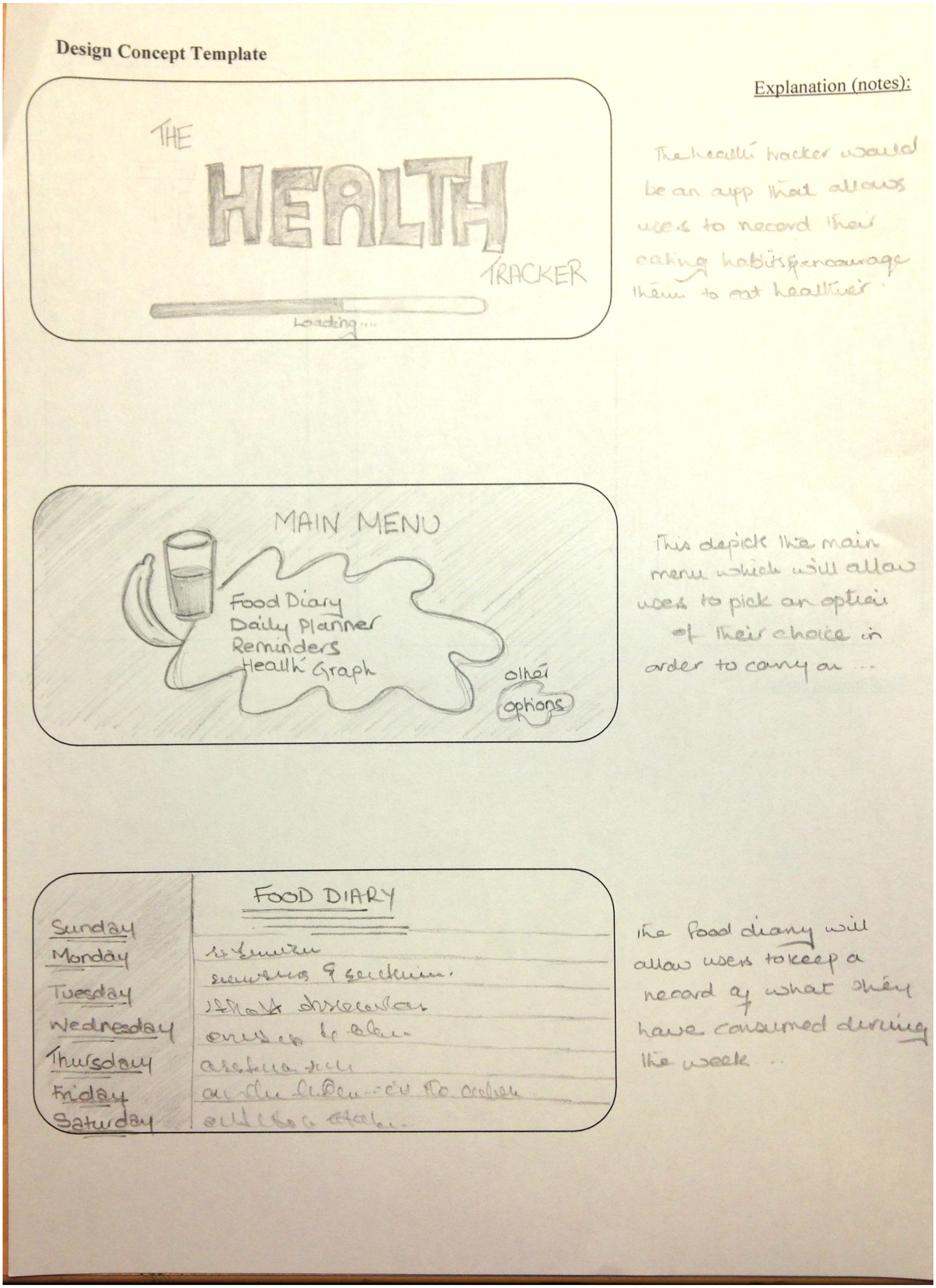

Figure 1: Example conceptual design (Group A, landscape template).

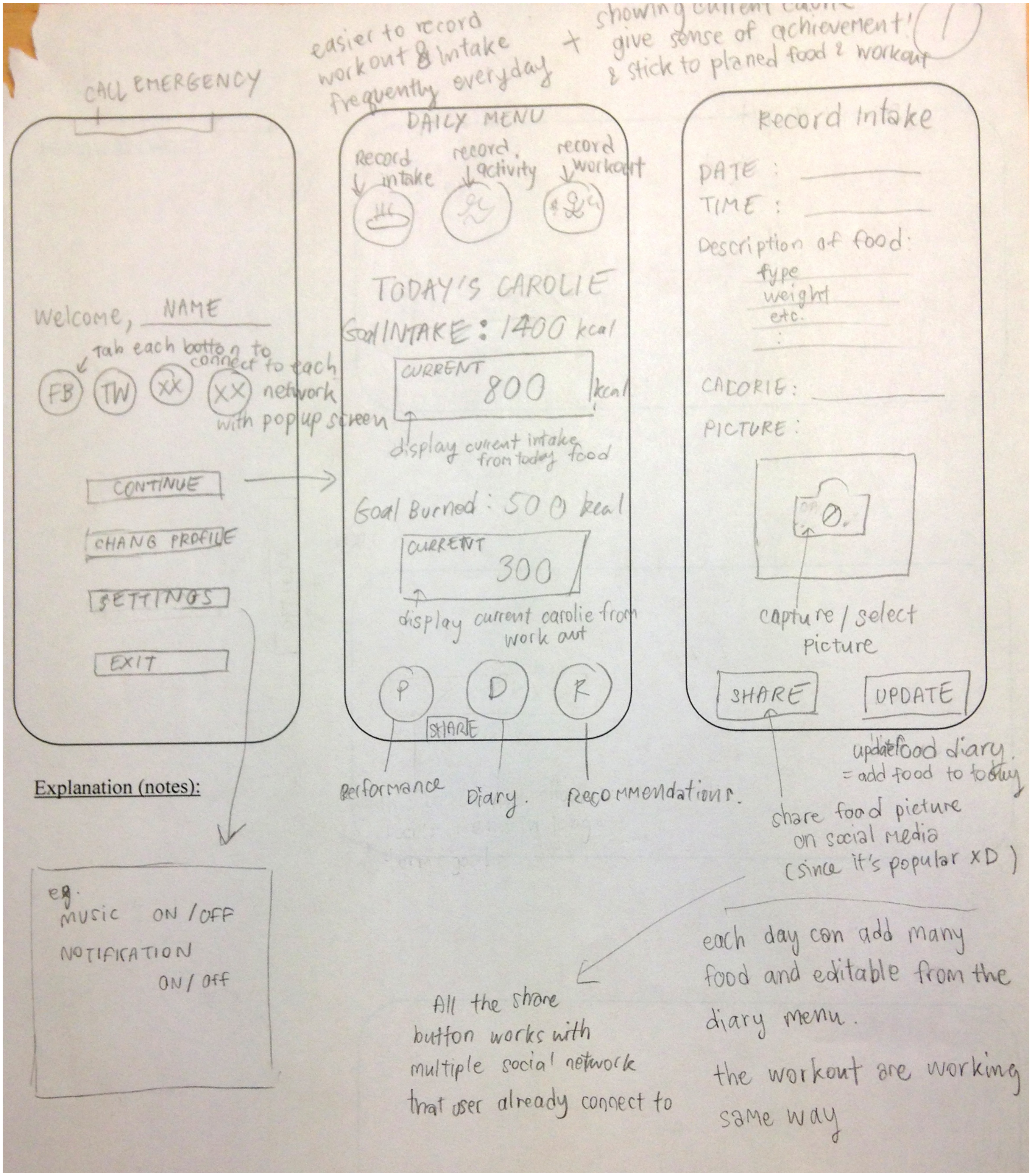

Figure 2: Example conceptual design (Group B, portrait template).

The combination of non-normal distribution and homogeneity of variance suggests using the Mann-Whitney U test. Mann-Whitney makes four assumptions, all of which are met:

1. The dependent variable should be measured on an ordinal or an interval level.
2. The independent variable should consist of two categorically independent groups.
3. A subject in each group should maintain absolute exclusivity and should not be subjected to treatment in another group.
4. The dependent variable exhibits homogeneity of variance.

Table 1: Grades Frequency

Grade	Group A ("Requirements")	Group B ("Ideas")
1	1	2
2	7	1
3	12	6
4	0	10
5	1	2
Mean	2.67	3.43
Median	3	4

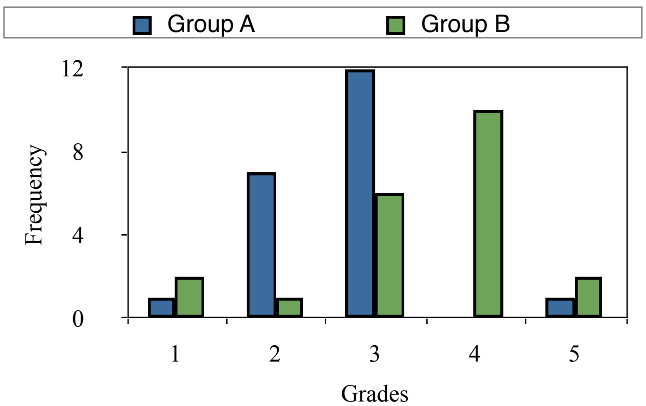

Figure 3: Grade Distribution across Groups

Table 2: Grades - Homogeneity of Variance

Levene's test	p = 0.183
Brown-Forsythe test	p = 0.354
Levene's non-parametric test	p = 0.089

Based on Mann-Whitney analysis we reject the null hypothesis (U=116.500, n=42, p=0.004). In other words, participants who received the "ideas" framing produced more creative designs by a statistically significant margin. Effect size (r) for the Mann-Whitney U test is calculated using Equation 1 where 'n' is the total number of samples. The result (r = 0.428) indicates a medium-high effect [33].

Equation 1: $$|r| = Z/\sqrt{n}$$

4.1 Exploratory Analysis of Fixation

Above, we theorized that framing desiderata as "requirements" would increase designers' propensity for fixation. While deep insight into the cognitive mechanisms underlying fixation would necessitate a different kind of study (e.g. a think-aloud protocol study), we included a simple indicator of fixation in the post-task questionnaire to facilitate some exploratory analysis. The question read "How important was the list of specifications in guiding your design?" and participants responded on a five-point scale from 1 (low) to 5 (high). We would expect participants in Group A to give the specification higher importance ratings than participants in Group B do. We also expect the importance placed on the specifications to be inversely related to originality.

First, Group A reported higher average importance of specification than group B (Table 3; Figure 4). This difference appears significant (Mann-Whitney U test, p=0.011; unequal variances t-test, p=0.006). However, results should be interpreted with caution as the data does not exhibit a normal distribution (as assumed by the t-test) or homogeneity of variance (as assumed by Mann-Whitney).

Table 3: Importance of Specification Frequency

Importance	Group A ("Requirements")	Group B ("Ideas")
1 (low)	0	3
2	1	5
3	2	3
4	12	6
5 (high)	6	4
Mean	4.10	3.14
Median	4	3

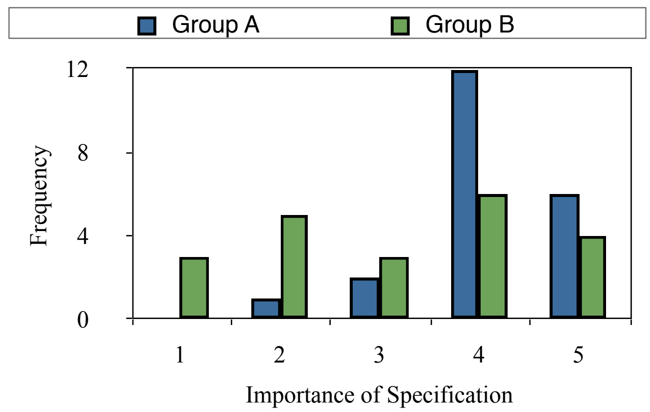

Figure 4: Grade Distribution across Groups

Second, participants who rated the importance of the specification as high (4 or 5 out of 5) produced less creative design concepts, on average (Table 4, Figure 5). The difference between these distributions is marginally significant (Mann Whitney U test, p=0.059).

In summary, exploratory analysis of fixation data suggest that framing desiderata as "requirements" increases fixation and that increased fixation may inhibit creativity. However, the evidence for fixation is not as strong as the evidence that requirements framing leads to less original design concepts and the statistical analysis of fixation presented here should be interpreted with caution.

Table 4: Grades Frequencies by Importance of Specification

	Importance of Specification		
Grade	**Low (1-3)**	**High (4-5)**	**Total**
1 (low)	0	3	3
2	2	6	8
3	5	13	18
4	5	5	10
5 (high	2	1	3
Mean	3.5	2.8	3.0
Median	3.5	3	3

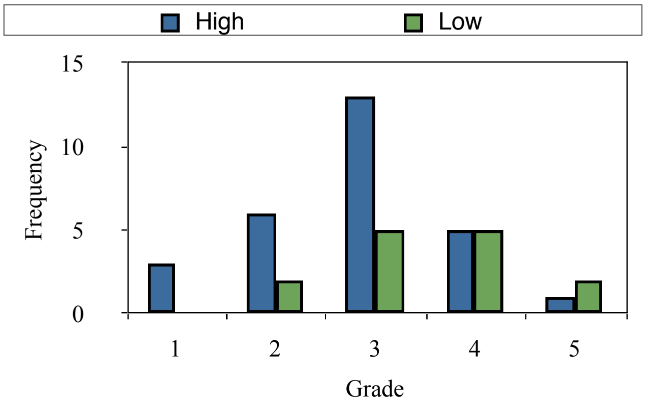

Figure 5: Grades by Importance of Specification

5. DISCUSSION

The above results strongly support a significant relationship between the way desiderata are framed and the originality of design concepts produced. In other words, simply using the terms "requirements specification" and "shall" may reduce design creativity.

Ralph [78] argued that requirements are a socially constructed illusion. Specifically, in many projects, success is not clearly understood; therefore, no one knows with any certainty which desiderata are necessary for success. Moreover, software teams do not have access to highly-experienced, well-trained requirements analysts. Therefore, real requirements documents often contain a mixture of goal statements, necessary conditions for success, meaningful but optional desiderata, design decisions and junk, i.e., desiderata that are irrelevant to actual goals. In practice, however, it may be impossible to differentiate necessary conditions for success from junk. Consequently, RE in practice is concerned not only with requirements but also with goals, desiderata that do not clearly relate to goals, high-level design decisions, obvious junk, non-obvious junk and generally understanding the domain.

Being potentially illusory does not necessarily imply that requirements are detrimental. Rather, the danger comes from a misalignment between the epistemic uncertainty of the desiderata and the skepticism of the designer. If requirements are highly certain but the designers treat them as dubious, they may produce artifacts that lack needed features. However, if requirements are uncertain but designers treat them as definitive, they may produce non-innovative artifacts.

While expert designers habitually treat given desiderata skeptically regardless of how they are presented [27] our study suggests that experienced (but not expert) designers are sensitive to the framing of desiderata. Specifically they are more likely to treat desiderata as more definitive if they are framed as "requirements" and more skeptically if they are framed as "ideas", with the latter leading to more creative designs. We theorize that this is related to mental-set fixation, where a practitioner restricts the use of his abilities (creativity) due to a situationally induced bias [42, 48]. As mental-set fixation is situationally-induced, altering requirements practices including framing may be effective in reducing fixation.

One unexpected difference between this study and similar studies of design fixation was in the number of design concepts produced by participants. Like previous studies, participants were asked to produce as many design concepts a possible. Unlike previous studies, however, all 42 participants in this study produced exactly one design concept. As we did not notice this behavior until after the task was completed, we can only assume that either the directions were unclear or the time was insufficient to allow for multiple design concepts.

Our findings should be interpreted in light of several limitations. The present study was devised to determine *whether* desiderata framing affects design creativity. While our exploratory analysis suggests that requirements fixation may be involved, further research is need to determine exactly *how* framing relates to design (see below). Moreover, as participants were not randomly sampled from a population, statistical generalization of results is not possible. Our participants' behavior may not generalize to experts. As we intentionally used a somewhat disorganized list of desiderata, some but not most of which may be necessary conditions for success, our results may not generalize to highly refined specifications or other kinds of models (e.g. use cases). Furthermore, this study focused on design concept *originality*, which is not equivalent to design concept quality and does not necessarily lead to original or high-quality implementations. Finally, the artificial setting in which the study took place may produce different dynamics than real software projects.

These limitations notwithstanding, our findings concerning requirements fixation and the relationship between desiderata framing and creativity have numerous implications for SE research, practice and education.

Previous research on design fixation has examined how providing designers with example solutions reduces their creativity. This study extends this stream of research by demonstrating that, even without examples, the framing of desiderata can negatively impact designers' creativity. This suggests at least three future research possibilities. First, while RE research traditionally focuses on the *quality* of requirements specifications, the *presentation* of desiderata also appears important. Presentation issues include not only modeling techniques (e.g. use cases, scenarios, goal models, agent models, IEEE-830 style "the system shall" statements) but also, as demonstrated here, the language used to convey them. Second, while RE research traditionally focuses on distinguishing mandatory desiderata (needs) and optional desiderata (wants), the epistemic status of desiderata appears equally important. That is, RE may benefit from techniques for indicating the epistemic status of a desideratum, e.g., *we are 80% certain that the system will need to support encryption*. Third, SE more generally may benefit from more research on debiasing (including de-fixating) developers and other software project actors. While debiasing is notoriously difficult [34], psychological research on epistemic rationality (calibration of belief to evidence [91]) may help. More generally, the use of the term *requirements* in the academic discourse may be over-rationalizing and oversimplifying the diversity of possible desiderata. Therefore, the RE vernacular may be obscuring innate disagreement and ambiguity in software projects, leading to inaccurate theories and ineffective methods.

For practitioners, our results suggest that the term *requirement* may curtail innovation independent of the requirements specifications themselves. If innovative solutions are preferred, desiderata should be framed to induce skepticism. While this study used a *list-of-ideas* framing, we do not advocate simply renaming "requirements" to "ideas" – the *ideas* language was chosen simply to minimize the difference between the two groups. Rather, we suggest the practitioners more generally consider two properties of each desideratum – importance/priority [43] and confidence [8, 56, 63]. Importance refers to how crucial a desideratum is for success. Confidence refers to the certainty of the desideratum's relevance. We suggest that non-expert designers interpret *requirement* as implying both high importance and high certainty. To promote innovation, the term *requirement* should therefore be reserved for desiderata that have high importance and high certainty. Based on our results, we can only recommend presenting less certain and less important desiderata in a manner that promotes skepticism and is appropriate to the particular context. However, this raises numerous questions for future research including *how do priority and confidence metadata affect fixation and creativity?* Moreover, we wonder about the mixed signals of giving a desideratum low confidence or low importance and still labeling it a *requirement*. While RE has increasingly recognized the ambiguity and volatility of desiderata in many domains, practitioners continue to exhibit (or feign) overconfidence in "requirements". This paper highlights the potential adverse effects of this overconfidence on innovation.

Similarly, software engineering education continues to present over-rationalized and oversimplified views of RE and design. The IEEE/ACM official model curriculum for undergraduate degrees in software engineering barely mentions design concept generation [75]. The notion that analysts 'elicit' requirements and designers translate those requirements into a system design is simply misleading. SE education should incorporate more training in creativity techniques, more realistically ambiguous projects and generally stop presenting deeply oversimplified views of software development. At the very least, students should be exposed to realistically imperfect requirements specifications and the need to distinguish legitimate requirements from junk requirements.

6. CONCLUSION

In summary, this paper investigated the question, *does framing desiderata as "requirements" negatively affect creativity in design concept generation?* The results of our exploratory experimental study strongly suggest that, yes, simply using the terms *requirements* and *shall* can deleteriously affect designers' creativity. This highlights the potential power of minor changes in vernacular and the sensitivity of designers to cognitive biases including framing effects.

Building on previous research on *design fixation*, we propose the concept of *requirements fixation*, i.e., disproportionate focus on explicit desiderata framed as requirements. While previous research (above) has demonstrated that designers may fixate on the features of given example designs, our research suggests that designers may also fixate on given desiderata. Like design fixation, requirements fixation may be mitigated by highlighting specific problems or the overall epistemic uncertainty surrounding given information.

More research is needed to clarify the relationship between desiderata framing, fixation and creativity. For example, fixation could be more directly demonstrated by an experiment comparing the creativity of designers given a goal and a set of "requirements" to a control group given only a goal. Moreover, think-aloud protocol studies [35], where participants explicate their thinking during a task through continuous speech, may provide insight into the cognitive mechanisms that mediate the framing-creativity relationship. Replications with novice and expert designers and confirmatory field studies are also needed. More generally, future studies may investigate related cognitive biases including anchoring, overconfidence and miserly information processing in software engineering contexts, not to mention approaches for debiasing participants.

In conclusion, this study highlights an innate tension between innovating, which comes from new ways of seeing the world, and satisfying explicit requirements, which are often rooted in a contemporary worldview. Meanwhile, despite all of the problems with requirements in principle and requirements specifications in practice, many researchers and practitioners continue to pretend that meeting requirements is the only, or at least the primary, dimension of software engineering success.

7. ACKNOWLEDGMENTS

Thanks are due to all of the participants and to the Lancaster University Management School for its financial support.

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