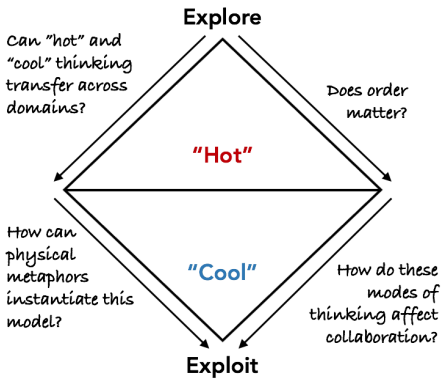

Figure 1: This diamond model of creative design shows a "hot" phase of divergent divergence and a "cool" phase of convergent exploitation. We hypothesize that novices insufficiently follow this approach.

Inventive Scaffolds Catalyze Creative Learning

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ABSTRACT

Creative problem-solving requires both exploratory and evaluative thinking skills. The contextual, open-ended nature of creative tasks makes them uniquely challenging to teach and learn. People tend to under-explore in problem-solving, using the most available representation of a problem and hindering potentially more creative solutions. My dissertation examines how inventive scaffolds provide feedback between the exploration and evaluation processes of creative problem-solving, potentially amplifying creativity of solutions. I investigate this through two interventions. First, interactive guidance and adaptive suggestions embodied in the CritiqueKit system to improve critique and evaluation of creative work. Second, problem-framing scaffolds to reduce fixation and enhance exploration. My research demonstrates methods for increasing human inventiveness with relevance in creative education and the design of creativity support interfaces.

KEYWORDS

Creativity; learning; feedback; scaffolds

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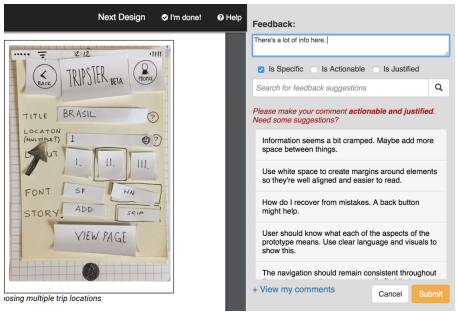

Figure 2: The CritiqueKit interface provides 1) interactive guidance of good feedback attributes (specific, actionable, and justified), and 2) adaptive examples of previously generated feedback.

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SCAFFOLDS FOR TACKLING COMPLEX CREATIVE PROBLEMS

Creative problem-solving engages both "hot" and "cool" thinking (exploration and exploitation), searching for novel solutions or hypotheses and evaluating whether they fit in new contexts. Computers can do this for well-structured problems where the truth is objective in all contexts (*i.e.* solving arithmetic problems, checking spelling errors). However, for complex problems that are highly contextual and ambiguous, human capability for inventiveness reigns supreme. My dissertation seeks to amplify this inventiveness through scaffolds that attune people towards nuances of complex problems to improve creativity. My thesis statement is that **making the connection between exploration and evaluation catalyzes more creative ideas** (Figure 1). My dissertation aims to contribute to a theoretical understanding of creative learning that supports human-computer synergy.

Inventive problem-solving instantiates creative thinking by engaging two mechanisms: searching a hypothesis space of a problem [3] (exploration), and embodying a hypothesis in a potential solution [9] (evaluation). These mechanisms help learners notice structural features and apply flexible problem-solving strategies. Prior work on invention as a learning strategy focuses primarily on well-structured problems, such as statistical formulas [11] or physics [2]. Scaffolding for domains with clear right or wrong answers will inherently be different from scaffolds for open-ended work, where the quality of solutions is measured by means other than distinct correctness. The challenge in teaching creative thinking is orienting people to an epistemological middle ground of understanding how to find the right design and how to get the design right [1].

My research will examine both content and process scaffolds for inventive problem-solving with the hypothesis that making the relationship between exploration and evaluation more explicit can improve creativity. My research investigates this hypothesis through two approaches: heuristic alignment for improving feedback on creative work, and problem-framing scaffolds for enhancing awareness of the exploratory and exploitative thinking processes in creative tasks.

RESEARCH OBJECTIVES & RESULTS

Interactive Guidance Techniques for Improving Creative Feedback

Effective feedback is crucial for improvement. Giving feedback is itself a creative problem-solving task; it requires analyzing the work's structure and prospectively generating concrete suggestions [8]. This process relates to the notion of exploratory and exploitative thinking in that reviewers must explore a

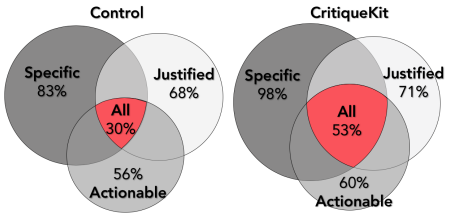

Figure 3: In a controlled experiment, participants with adaptive suggestions and interactive guidance gave a significantly higher percentage of feedback considered Specific, Actionable, and Justified (53%) compared to participants without these scaffolds (30%).

space of possible features to critique and then exploit relevant features to provide detailed feedback. However, people are not consistently skilled at providing good structural feedback, instead focusing on surface features because they require less analysis to see and critique [6]. To investigate whether interactive tools can help reviewers transcend this challenge, we developed CritiqueKit. CritiqueKit introduces two scaffolding techniques. First, CritiqueKit checks whether draft feedback fits three attributes, displaying this in checkboxes (Figure 2). Second, CritiqueKit presents contextually-relevant examples of previously generated good feedback.

Through two classroom deployments and two controlled experiments, we found that adaptive suggestions and interactive guidance lead to more specific, actionable, and justified feedback (Figure 3) [7]. These findings suggest that adaptive examples can focus reviewers towards deep features of the work, making these examples more applicable. In addition, our results demonstrate that interactivity in learning systems should take the learner's context into account to provide more relevant assistance.

Problem-Framing Scaffolds for Improving Exploration

The diamond model of creative thinking points to a relationship between "hot" and "cool", exploratory and exploitative, thinking (Figure 1). In open-ended problems, people often tend to under-explore and satisfice in their problem-solving strategy [12]. I hypothesize that people under-explore because they don't want to "waste" time on paths not taken. However, creative work almost by definition includes some uncertainty about which approaches may be most effective, or even what "effective" is. One benefit of prototyping is that it can efficiently shed insight on these uncertainties [4]. Under-exploration yields fewer conceptual leaps and consequently, underwhelming outcomes [13]. The following three proposed experiments examine scaffolds that help learners re-frame problems to increase exploration. I hope this work will both make theoretical contributions and contribute principles for designing creativity support tools.

Hot & Cool Thinking Strategies: The first experiment examines whether the order of exploration and exploitation matter in how problems are framed. This within-subjects experiment will adapt problem-framing tasks used by the Stanford dschool [5]. First, participants are asked to list the most important and essential attributes of a familiar experience, such as a restaurant. Participants then brainstorm ideas for a restaurant without the most important attribute (exploration) or ideas for a restaurant that highlights the most important attribute (exploitation); the order of these scaffolds are counter-balanced. Participants then generate a single restaurant design by choosing or consolidating among their brainstormed ideas. I hypothesize that asking participants to employ an exploration-first ideation process produces more novel ideas than encouraging early exploitation. A further extension of this experiment could be to examine how problem-framing scaffolds can impact collaboration on creative tasks. How might making the phases of exploration and exploitation more explicit impact the

About Me: I am a fourth-year Ph.D candidate at UC San Diego in Cognitive Science, advised by Dr. Scott Klemmer. My research investigates inventive scaffolds to improve exploratory and evaluative thinking. This thesis will contribute a theoretical understanding of creative learning that will influence the design of tools for augmenting and amplifying creativity.

My career goals following the completion of my dissertation include faculty positions in learning sciences departments and information schools. I hope to gain feedback on positioning my research within these goals at this doctoral consortium.

Dissertation Status & Next Steps: I have completed one set of studies, the results of which have been published at CHI 2018 (Honorable Mention Award) [7]. I am currently conducting the last set of studies and plan on completing my dissertation by the end of Summer 2020.

Acknowledgements: Thank you to my advisor Dr. Scott Klemmer, collaborator Dr. Caren Walker, and colleagues in the Design Lab and Cognitive Science Department.

way people ideate and generate in creative work? These studies will provide empirical evidence on the relationship between process scaffolds, creativity, mental representations, and design outcomes.

Transfer of Creativity: A seeming paradox of creative cognition is that people are simultaneously very good and very bad at transferring knowledge into new domains [10]. A grand challenge for learning science research is to identify strategies that catalyze transfer. This experiment investigates the efficacy of problem-framing scaffolds on *transfer* in creative tasks. Prior work in the learning sciences suggests that invention activities can facilitate far transfer through their preparatory effects on learning [11]. This experiment will investigate whether inventive scaffolds can similarly enhance far transfer on more open-ended problems or whether the benefits of such process-oriented scaffolds are domain-specific. The results of this study has theoretical implications for whether exploratory and evaluative processes in creative thinking are more domain-general or whether they are localized within specific problem domains.

Physical Metaphors of Hot & Cool Thinking: This last experiment will investigate if physical metaphors of the "hot" and "cool" thinking framework can lead to greater creativity. The notions of exploratory and exploitative thinking are inherently abstract; metaphorical embodiments of these phases of creative thinking might aid in making the process more concrete. An example of this could be using color coding or analogies such as thermometers or faucets to examine whether these physical models effectively induce exploration or exploitation during creative thinking tasks. These results have practical implications for interface design of creativity support tools and educational systems within creative domains.

Current & Expected Contributions

My dissertation research will articulate principles that help learners improve their design thinking and creative work. My work will also show the instantiation of these principles in software creativity support tools. Ultimately, I hope to influence the development of pedagogical methods, the design of creativity support tools, and the practice of innovation in professional settings.

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