A White Paper for Future Directions in CS Education Research Summit

Investigating and Understanding the Role and Impact of Creative Thinking and Competency on Improving CS Education

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1. Rationales

Computational thinking is vital to today’s education to better equip students with the competitive skills to do well in our increasingly data-intensive and digital industries (cf. Rising above the Gathering Storm, 2007) and is a skill as fundamental as reading, writing, and arithmetic to every child’s analytical ability (Wing 2006). As reported in a workshop on computational thinking, by explicitly articulating concepts such as abstraction and modeling many computer scientists believe “it is possible to describe a collection of analytic skills that everyone, not just computer scientists, can use to help solve problems, design systems, and understand human behavior.” (National Research Council 2010). Further, they argue that “computational thinking is comparable in importance and significance to the mathematical, linguistic, and logical reasoning that society today agrees should be taught to all children.”

In the way that computational thinking is not just for computer scientists, but for everyone, creative thinking should be an essential aspect of any problem solving process. Creative thinking, as evidenced by the work of experts in many fields, is not an innate talent or the province of just a few individuals, and it is not confined to the arts. Rather, it is a process which is an integral component of human intelligence, which can be exercised within any context and which can be practiced, encouraged and developed (Epstein 1996; Epstein et al. 2008; Shell et al. 2010). “Creative thinking is thinking patterned in a way that tends to lead to creative results. This definition reminds us that the ultimate criterion for creativity is output. We call a person creative when that person consistently gets creative results, meaning, roughly speaking, original and otherwise appropriate results by the criteria of the domain in question.” (Perkins 1984, pp. 18-19).

In our framework, both computational thinking and creative thinking are viewed as cognitive tools. Specifically, computational thinking includes conceptualizing at multiple levels of abstraction, defining and clarifying a problem by breaking it down into relational components, and testing and retesting of plausible solutions. Similarly, Epstein (1996, 2005, Epstein et al. 2008) notes that creative thinking involves core cognitive competencies of capturing novelty, challenging established thinking and behavior patterns, broadening knowledge beyond one’s discipline, and surrounding oneself with new social and environmental stimuli. Computational tools link to Epstein’s creative competencies by providing analytical and logical processes to STEM students and faculty that broaden knowledge by providing new problem solving tools, challenge established disciplinary problem solutions, surround students in interdisciplinary activities by looking at knowledge and information in new ways, and finally provide tools and methods for systematically capturing and saving novel data and problem solutions. Creative competencies in turn expand the tools available to the computer scientist
or CS student by challenging existing algorithmic approaches, broadening possible solutions by presenting alternative ways of framing and thinking about problems, surrounding CS students with expanded social and environmental stimuli through interdisciplinary work, and enhancing students’ ability to capture and document novel problem solutions and coding ideas.

2. Existing and On-Going Work

Two NSF-funded projects (one previous and one on-going) have contributed to this white paper. Renaissance Computing was a planning grant aimed at investigating how to better design and implement CS curricula with interdisciplinary flavors. Integrating Computational Thinking and Creative Thinking (IC2Think) has continued the innovation of CS1 courses by developing classroom exercises that combine learning computational thinking with developing creative competency through collaborative hands-on problem solving coupled with written analysis and reflection.

Renaissance Computing led to re-organization of the CS core courses and informatics courses at the university and to several studies on the impact of contextualized CS1 in student learning of CS concepts (Soh et al. 2009; Shell & Soh 2013; Husman & Shell 2011; Muto-Nelson et al. 2013).

The IC2Think project (Soh et al., in press) has developed seven exercises that are currently being integrated into a stand-alone course for a proposed Informatics Minor at the University of Nebraska, Lincoln. We also are exploring developing a MOOC based on this suite of exercises. Five of the exercise modules have been placed on Google's Exploring Computational Thinking site, allowing for broad dissemination to the K-16 community. Also, we have also made the exercises available on the Ensemble Project website for dissemination.

Our IC2Think study (Shell et al., in press) is one of the first to look at the impact of creative thinking on student achievement and student strategic self-regulation in a STEM course (CS1). Our proposition is that using Epstein’s model, creative competency can improve learning of computational thinking and our findings provide support for this contention. Creative competency was not associated with grades, but was associated with higher retention of course material. Also, creative competency was associated with higher self-regulated strategy use and knowledge building. These results suggest that creative competency may enhance the strategic learning strategies associated with building new knowledge and understanding that lead to greater long-term retention and development of expertise. This suggests that enhancements to creative competency may be a valuable instructional tool.

Furthermore, our findings also indicate an apparent “dosage” effect, i.e., learning and course achievement increase with each additional creative thinking exercise completed. The increases are not trivial (Miller et al., in press). Students completing two or fewer exercises averaged approximately a C; whereas, students completing three exercises averaged a B and those completing four averaged almost a B+. Similarly, students improve by about 1 1/2 points from 0-1 to 2-3 exercises completed and another 1 1/2 points on the knowledge test from 2-3 to 4 exercises completed. In relation to traditional findings for classroom educational interventions, these are strong effects. They also demonstrate meaningful “real world” impact. Of course, we cannot conclusively determine that the results are solely due to the exercises; however, by controlling for students’ cumulative GPA, we can say that the results are not due to students who are better students in general completing more exercises than poor students.
3. Future Directions in CS Education Research: The Role of Creative Competency

Grounded in our rationales and enlightened by the findings from our existing and on-going work, we propose as a future direction in CS education research to investigate the role of creative competency in CS education. Specifically, we believe it is important to investigate further the role of creative thinking in CS education and also the role of integrating both computational and creative thinking in CS education. The importance of these investigations is further supported by the promising results that we have so far achieved.

- **Impact of Creative Thinking on Learning CS Concepts** We want to continue to conduct more research into whether incorporating creative thinking in CS education improves student learning of CS concepts, as well as the role of creative competency in learning such concepts. Longitudinal studies, including all levels of CS courses in addition to just introductory CS courses, for majors, minors, and non-majors, are needed to study whether and how creative thinking plays a role in student learning with different backgrounds, motivation, self-efficacy, and self-regulation. We are also interested in the impact creative thinking could have upon K-12 CS education.

- **Delivery of Creative Thinking** In our current IC2Think project, we utilize collaborative creative thinking exercises which require hands-on activities, coupled with “lightbulbs” that tie the activities to CS concepts, and which are followed by questions requiring student reflection and analysis. Are these the best ways to integrate creative thinking and teach students about Epstein’s four skills of creative thinking? Which exercises impact student learning more? What properties are important?

- **Assessment** How should student creative thinking skills be assessed?? What sort of creative problem solving applications can be used to evaluate them? Are there qualitative or quantitative measures or tests that can be used to accurately assess student creative thinking skills? Can online or peer-based approaches accurately assess student creative thinking skills?

- **Collaborative Learning** Our current creative thinking exercises are administered to groups or teams of students. But it is not yet clear how collaborative learning interacts with the learning of creative thinking skills, and in turn, with computational learning. Does collaboration help students learn creative thinking skills? How could or should one leverage peer teaching and learning into learning creative thinking?

- **Recruitment and Retention** Including creative thinking topics can be seen as non-engineering and non-CS-like. For example, we have found (anecdotally) that some students complain about having to do the IC2Think creative thinking exercises. However, will these exercises help us recruit more students into CS because of their appeal? Will these exercises help us retain more students in CS because of their connections to real-world contexts? Will an increase in creative thinking skills encourage students to problem solve better and entice them to commit to CS even more strongly? What role should creative thinking exercises as well as creative thinking play in outreach and in getting K-12 students interested in CS?

- **Technology-enabled** Presently, we deliver our IC2Think creative thinking exercises on a Wiki platform, equipped with rating, tagging, discussion forums, learning object administration, and general computer-supported collaborative learning features. How can
and should technology help deliver creative thinking exercises? What features of technology could help support students in exploring and learning? What features would limit their activities? Can social networking tools help and how? Can web-based technologies—via smart phones, tablets, or conventional laptops—help support the learning of creative thinking skills, and help to leverage available digital information? Can cloud technologies leverage repositories of creative artifacts to help design more comprehensive and in-depth exercises for students? Can better “lightbulbs” be collected to couple creative thinking to CS concepts in more intuitive or insightful ways?

- **Women and Under-Represented Groups** Will creative thinking be thought of as more gender-friendly and thus put students of different genders on a more level playing field? Will it encourage women students to major and succeed in CS? Will teaching students to be creative and inculcating in them self-efficacy and awareness of their own creative thinking skills improve their success in CS, especially for students from under-represented groups?

- **MOOCs** In the face of massively open online courses, how could teaching creative thinking skills be offered online to a large classroom of students? A MOOC would present unique challenges in content delivery, learner support, performance assessment, and administration but would also facilitate wide-scale delivery.

- **Curricular Investigation** We are excited about the role of creative thinking in the long-term development of CS curricula. With today’s applications becoming increasingly interdisciplinary, creative problem solving is often necessary to investigate, study, seed, and optimize (outside-the-box) solutions to open-ended questions. Just as the senior capstone experience is a must in today’s CS curricula, we see a similar importance for creative thinking. However, integrating creative thinking into the CS curriculum is non-trivial. What should be taught? How much should be taught? How broadly or deeply? What should be the learning objectives and outcomes? Further, how can creative thinking help bridge applications or contexts to better motivate students participating in computing, in interdisciplinary curricula (CS + music, CS + arts, CS + humanities, etc.)

4. **Summary**

We have stated the rationales behind our proposed future direction for CS education research, emphasizing the significance of creative thinking and the integration of creative and computational thinking to learning in general and to learning of CS concepts in particular. We subsequently presented a brief overview of our work, particularly, our IC2Think project that has produced promising results on the impact of creative thinking exercises on student learning in CS1 courses. Finally, we have submitted nine aspects of our proposed CS education research topic to investigate the role, design, and challenges of creative competency in CS education.

5. **Acknowledgement**

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6. References


