Supporting Computational Algorithmic Thinking (SCAT): Exploring the Development of Computational Algorithmic Thinking Capabilities in African-American Middle-School Girls

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Abstract: Computational algorithmic thinking (CAT) is the ability to design, implement, and assess the implementation of algorithms to solve a range of problems. It involves identifying and understanding a problem, articulating an algorithm or set of algorithms in the form of a solution to the problem, implementing that solution in such a way that it solves the problem, and evaluating the solution based on some set of criteria. This report introduces and describes CAT as explored through the Supporting Computational Algorithmic Thinking (SCAT) project, an on-going longitudinal between-subjects research project and enrichment program that guides African-American middle school girls through the iterative game design cycle resulting in a set of complex games around broad themes.

Introduction

Jeanette Wing (2006) defines computational thinking as *"a way humans solve problems…"*. This research makes explicit a critical aspect of computational thinking through its focus: the design, development, and implementation of algorithms to solve problems. An algorithm is defined as a well-ordered collection of unambiguous and effectively computable operations that, when executed, produces a result and halts in a finite amount of time (Schnieder & Gersting, 2010).

Computational algorithmic thinking (CAT) is the ability to design, implement, and assess the implementation of algorithms to solve a range of problems. It involves identifying and understanding a problem, articulating an algorithm or set of algorithms in the form of a solution to the problem, implementing that solution in such a way that it solves the problem, and evaluating the solution based on some set of criteria. CAT has roots in Mathematics (Polya, 1973), through problem solving and algorithmic thinking (Kramer, 2002). CAT lies at the heart of Computer Science, which is defined as the study of algorithms (Schneider & Gersting, 2010). CAT embodies the ability to think critically and creatively to solve problems and has applicability in a range of areas from Computer Science to cooking to music (ISTE NETS.S, #4, 2007; Polya, 1973; Wing, 2010).

Supporting Computational Algorithmic Thinking (SCAT) is a longitudinal between-subjects research project exploring how African-American middle-school girls develop CAT capabilities over time in the context of game design. SCAT is also a free enrichment program designed to expose middle school girls to game design. The goals are: 1) to explore the development of computational algorithmic thinking over three years in African-American middle-school girls as they engage in iterative game design, and 2) to increase the awareness of participants to the broad applicability of computational algorithmic thinking across a number of industries and career paths. Spanning three years, participants, called SCAT Scholars, develop CAT capabilities as they design more and more complex games. SCAT Scholars begin the program the summer prior to their 6th grade year and continue through their 8th grade year. They engage in 3 types of activities each year: 1) a two-week intensive game design summer camp; 2) Two (2) six-week technical workshops where Scholars implement the games they have designed using visual and programming languages in preparation for submission to national game design competitions; and 3) field trips where Scholars learn about applications of CAT in different industries and careers. This work aims to explore the following research questions:

1. How do individual and small-group computational algorithmic thinking capabilities of African-American middle school girls develop over time?
2. What difficulties do learners face as they engage in computational algorithmic thinking?
3. What do those difficulties suggest about supporting learners as they engage in computational algorithmic thinking?
4. How does participating in SCAT impact participants' perspectives of computational algorithmic thinking as well as their perceptions of themselves as problem solvers and game designers?

Game design has been chosen as the domain for a number of reasons. First, game design is a domain with which middle-schoolers have a great deal of familiarity as consumers (Kafai, 2006; Irvine, 2010). The Pew Internet & American Life Project's survey revealed that among young people, ages 12 – 17, 97% of respondents play video games (Lenhart, Kahne, Middaugh, Macgill, Evans & Vitak, 2008). As such, this domain can provide motivation as learners "look under the hood" of their favorite games to understand how they are designed and implemented. Second, game design is centered around the iterative design, representation, and implementation of algorithms, which makes it an ideal domain to understand and describe the development of

CAT over time (Crawford, 2010). Third, based upon industry practices, game designers iteratively move from game conceptualization to production and release over time (Fullerton, et. al., 2004), making game design an ideal domain for conducting longitudinal studies. Lastly, game design is a domain in which African-American women are grossly under-represented (Brathwaite, 2009). Despite the fact that, of the 97% of young people who stated they played games in the Pew Institute's survey, over 94% of girls play video games with little difference in the percentages by race, ethnic group, or socio-economic status (Lenhart, Kahne, Middaugh, Macgill, Evans & Vitak, 2008), women represent only about 10 – 12% of the game design workforce, and Latinos and African-Americans comprise less than 5% combined (Plutzik, 2010).

While there is a great deal of research that examines how to engage students in computational thinking and learning in Computer Science (CS) or that focuses on how game design improves IT fluency, algorithmic thinking, collaboration, programming capability, and broader participation from under-represented groups, there is a scarcity of research that focuses on understanding and describing how the development of CAT happens over time as a complex cognitive capability (Repenning & Ioannidou, 2008; Owensby, 2006; Thomas, 2008; Werner, Campe & Denner, 2005; Maloney, Burd, Kafai, Rusk, Silverman & Resnick, 2004; DiSalvo, Guzdial, Mcklin, Meadows, Perry, Steward & Bruckman, 2009; Barnes, Richter, Chaffin, Godwin, Powell & Ralph, 2007; Kafai, 2006; Koschmann, et. al., 1996; Papert, 1993). Furthermore, there is less research that focuses on understanding how the development of these kinds of complex cognitive capabilities can impact not only how we leverage game design to teach and support students as they develop these capabilities, but also how we define and measure the learning that happens during that development.

This report describes the SCAT project, which is in the first of three years of data collection. The next section of this report will provide the background context that grounds the research. Then, the SCAT learning environment, including the scaffolds that support Scholars as they engage in game design, is described. As this work is in its first year, this report does not currently have any findings or results to share. Instead, this report is designed to introduce computational algorithmic thinking as a complex cognitive capability and SCAT as a project and program designed to develop CAT within this population, similar to Maloney, et. al (2004).

Background

The National Research Council (NRC, 2011), in their report entitled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea*s, outlines eight practices as being "essential elements of the K-12 science and engineering curriculum". Among them are: defining problems, developing and using models (physical or mathematical models and prototypes), planning and carrying out investigations, analyzing and interpreting data, using mathematics, information & computer technology, and computational thinking, designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information. While the major competencies that students should have by the 12th grade and sketches regarding how that competence should progress are described, the NRC identifies that those sketches are based on The Committee on a Conceptual Framework for New Science Education Standards' judgment as "there is very little research evidence as yet on the developmental trajectory of each of these practices" (p. 3-6).

As a domain, engaging in game design aligns with the eight practices outlined by the NRC (2011). The iterative game design lifecycle involves several phases, which are also iterative (Fullerton, et. al., 2004). During brainstorming, game designers generate many ideas for games and present those ideas. Once an idea is selected, paper-and-pencil drawings are created, called storyboards, that include demo artwork. Playtesting is next, which involves bringing actual players from the target user group in and observing them as they play the game (or engage with the storyboard) in real time, getting feedback about the game experience to inform the design of the game (Fullerton, et. al., 2010; DiSalvo, Guzdial, Mcklin, Meadows, Perry, Steward & Bruckman, 2009). Next, game designers create a playable physical prototype using paper-and-pencil and/or craft materials. Then, a rough software prototype is created which models some aspect(s) of core gameplay. Then follows more playtesting. Next comes creating the design document, which outlines every aspect of the game and how it will function. This is followed by implementing the game with playtesting throughout implementation. Finally, quality assurance testing is done with continued playtesting.

The acquisition and development of skills, capabilities, and practices involves the changing of declarative knowledge, or independent pieces of factual knowledge, to procedural knowledge, or connected knowledge that forms a process for carrying out a skill (Anderson, Kline, Greeno & Neves, 1981; Anderson, 2000). Applied in context and/or among a community, a process evolves into a practice (Nersessian, 2008; Lave & Wenger, 1991). While skills, or abilities refer to what one can do in the present, capabilities refer to what one can learn to do with instruction and support, or scaffolding (Bandura, 1994; Bandura, http://des.emory.edu/mfp/self-efficacy.html#bandura, Vygotsky, 1978; Bransford, Brown & Cocking, 1999, Tabak, 2004). However, moving learners from capability to ability requires several things (Bransford, Brown & Cocking, 1999; Owensby, 2006; Thomas, 2008). First, learners need opportunities to make connections between their experiences and the knowledge or skills they are learning. Second, learners need enough time to learn and develop skills and capabilities so that they can use them flexibly in appropriate situations. Third, learners should be supported as they attempt to represent problems at higher levels of abstraction. Finally, learners should be encouraged to monitor their learning and should be supported as they learn metacognitive strategies.

SCAT Learning Environment

The facilitator plays a major role in the development of Scholars' CAT capabilities in the SCAT learning environment, as she serves first as the primary modeler and then as a just-in-time coach (Collins, Brown & Newman, 1989). In addition, the facilitator leads and supports discussions that help Scholars as they think through their designs, helps them make connections across dyad experiences and problems, and models the kinds of questions Scholars should be asking themselves and their peers as they develop algorithms for their game designs, move through the iterative game design cycle, and reflect on their use of CAT (Koschmann, et. al., 1996). As dyads work on their game designs, she walks from group to group asking them questions about their designs, helping them identify problems and issues, illustrating for them how to use the Design Notebook and other tools and resources provided to them to help them design their games, and serves as a sounding board for dyads as they design. Although the facilitator is a critical component to the SCAT learning environment, she cannot be with every group or individual all the time. To help overcome that limitation and to help Scholars develop more expert CAT capabilities, the Design Notebook has been created to coach Scholars as they engage in CAT through game design. The Design Notebook has been integrated into SCAT activities, affording Scholars multiple opportunities to develop CAT capabilities while working individually and collaboratively in dyads.

The Design Notebook contains paper-and-pencil based tools that coach groups and individuals in the ways cognitive apprenticeship suggests (Collins, Brown & Newman, 1989; Puntembekar & Kolodner, 1998) by using a system of scaffolds (Owensby, 2006; Thomas, 2008). Each scaffold in the system supports groups and individuals in a particular way and addresses a particular difficulty that learners may face when engaging in complex cognitive skills, processes, and capabilities like designing an experiment, interpreting and applying the experiences of experts, or engaging in CAT. The system of scaffolds has 5 parts (Owensby, 2006; Thomas, 2008). First, tool sequences make process sequence visible. This scaffold addresses the structuring of tools to suggest a high-level process that learners are engaging in. Second, within each tool, structured questioning or statements make the task sequence clear. This scaffold addresses prompts, which are questions or statements used to focus learners' attention as they are carrying out or reflecting on a task. Third, for each prompt in the sequence, hints are provided. Hints are task-specific/domain-specific questions or statements used to refine a task. Fourth, for each prompt in the sequence, examples are provided. Examples are exemplars that can be used to model a process or a specific step of a process. Fifth, for some tasks in the sequencing, a template or chart to help with lining up one's reasoning is provided.

Given that Scholars will be able to move through the iterative game design cycle at their own pace, it is likely that those Scholars or dyads who are further along in the game design cycle will be able to scaffold dyads who are not as far along (Vygotsky, 1978; Roschelle, 1996; Owensby, 2006; Thomas, 2008, Palinscar, 1984). In addition, different Scholars will bring different perspectives to the dyad, which will contribute to greater understanding by the dyad. The literature shows that small group collaboration and discussion has many benefits (Feltovich, Spiro, Coulson & Feltovich, 1996; Koschmann, Kelson, Feltovich & Barrows, 1996; Roschelle, 1996; Bayer, 1990; Wells & Chang-Wells, 1992; Barron, et. al, 1998, Barron, 2003).

Current Project Status and Next Steps

We are currently working with 20 African-American sixth grade girls who attend various schools across the metro-Atlanta area. The SCAT project kicked off its first year of data collection this past summer (July 2013) beginning with a two-week summer camp. During the camp, Scholars were introduced to the game design cycle and engaged in brainstorming, storyboarding, and physical prototyping. They designed games for social change that address a range of topics from environmental sustainability to bullying. Scholars used the full range of scaffolds, including asking questions of the facilitator, using the Design Notebook, and each other as they not only engaged in whole class discussions, but also as they participated in gallery walks (Kolodner, et. al, 2003), where Scholars interacted one-on-one, playtested each other's games, and gave feedback to inform the next iteration of design. On the last day of camp, Scholars visited the Aware Home on the campus of Georgia Tech, which is an "intelligent" home as well as a research project aimed at exploring various technical, design, and social issues that people face in a home setting. Scholars toured the home, learned about the different algorithms that were designed and implemented to run the home, and interacted with undergraduate/graduate students who design, implement, integrate, and maintain those algorithms.

During the Fall 2013 semester, Scholars participated in monthly SCRATCH workshops, learning about the SCRATCH environment and programming common game functionality using SCRATCH (e.g., moving the player from one level to the next; creating the look and behavior of a sprite; and creating a scrolling scene). Beginning in February, Scholars will engage in two 6-week workshops where they will develop design documents, implement their games using SCRATCH, and submit their games to two different national game design competitions. The 2014 STEM Video Game Challenge aims to motivate interest in STEM learning among America's youth by tapping into students' natural passions for playing and making video games. It was initiated in response to President Obama's initiative to promote a renewed focus on STEM education, the Educate to Innovate Campaign. Scholars can either submit written design documents or playable game prototypes. Scholars will submit both design documents and playable game prototypes to the Future Game Designers Competition.

As Scholars engage in SCAT activities, we have and will continue to collect video observations (both whole class and dyads as they work together), artifacts they create, survey data (pre- and post), and interview data (from both the facilitator as well as the Scholars) as data. Video observations allow us to have a visual record of the enactment, see Scholars struggle with CAT through game design, and reveal the discussions they are engaging in as they work, providing a link between what students talk about and what they write about in their Design Notebooks (Owensby, 2006; Thomas 2008). Observations also uncover the effects of the Design Notebook on both individual and dyad CAT development. Scholar artifacts (e.g., Design Notebook, physical prototypes, software prototypes, etc.) uncover how CAT capabilities develop over time. Pre-suveys asses Scholars' awareness of careers and opportunities related to CAT prior to SCAT. Post-surveys assess SCAT's impact on career and opportunity awareness related to CAT. Interview data will uncover both Scholars' understanding of what CAT is, how they have enacted it in the course of their activities, and their perceptions of themselves as problem solvers and game designers as well as facilitators' perceptions of Scholars' CAT capability development, their experience facilitating SCAT activities, and feedback to inform those activities.

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