Supporting Computational Algorithmic Thinking (SCAT): Understanding the Development of Computational Algorithmic Thinking Capabilities in African-American Middle-School Girls Through Game Design

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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 paper not only introduces and describes CAT as explored through the Supporting Computational Algorithmic Thinking (SCAT) project, but it also presents insights from preliminary analysis of the data. SCAT is 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 with themes focused on social change.

Categories and Subject Descriptors

K.3.2 [**Computers And Education**]: Computer and Information Science Education

General Terms

Algorithms, Design

Keywords

computational algorithmic thinking, SCAT, game design, African-American, middle-school, girls.

1. 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 [4], through problem solving and algorithmic thinking [3]. CAT lies at the heart of Computer Science, which is defined as the study of algorithms [5]. 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 [2, 4, 6, 7].

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?

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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 [18, 17]. The Pew Internet & American Life Project's survey revealed that among young people, ages 12 – 17, 97% of respondents play video games [22]. 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 [12]. Third, based upon industry practices, game designers iteratively move from game conceptualization to production and release over time [15], 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 [10]. 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 [22], women represent only about 10 – 12% of the game design workforce, and Latinos and African-Americans comprise less than 5% combined [31].

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 [32, 24, 36, 40, 23, 13, 6, 18, 19, 28]. 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 paper describes the SCAT project and presents findings from our preliminary analysis of data from SCAT Season 1 and some data from Season 2 [37]. The next section 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. Next, we will explore the data currently being collected and how we are analyzing it. Then, we will present some very preliminary insights from early data analysis efforts. Finally, we will discuss what these insights may be suggesting in terms of on-going data analysis and future work.

2. BACKGROUND

The National Research Council [25], 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 [25]. The iterative game design lifecycle involves several phases, which are also iterative [15], as shown in Figure 1. 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 [15, 13]. Next, game designers create a playable physical prototype using craft materials, which is also playtested. 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. Figure 1's representation of the game design cycle is a more fine-grained articulation of Fullerton, et. al's [15] design-implement-playtest model. Our representation describes in more detail what happens during the design-implement-playtest model, and appears to be a more appropriate representation for this population (i.e., middle-school girls who have never designed, impelemented, or playtested games before) as well as for the goals of this research (i.e., understanding the development of CAT).

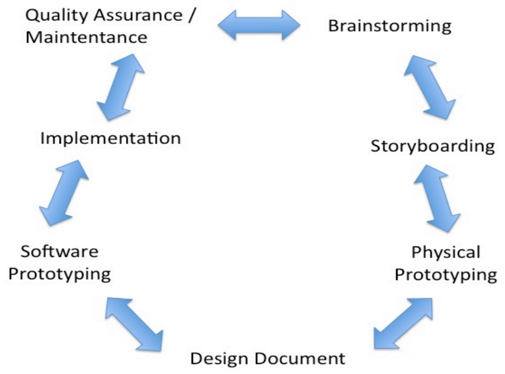


Figure 1: The Game Design Cycle

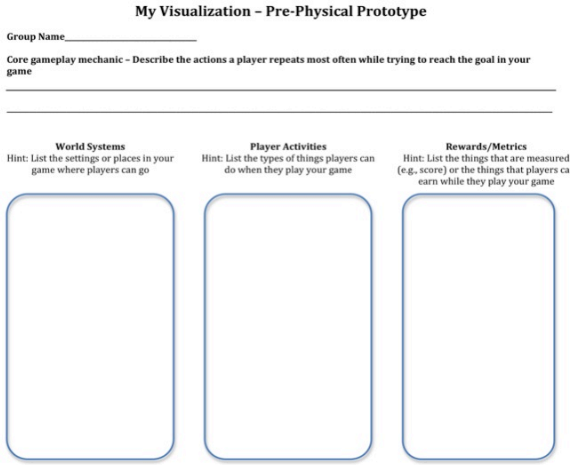
The acquisition and development of skills, capabilities, and practices involves the changing of declarative knowledge, or independent pieces of factual knowledge, to procedural knowledge, or connected knowledge that forms a process for carrying out a skill [2, 1]. Applied in context and/or among a community, a process evolves into a practice [21]. 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 [3, 4, 38, 9, 35]. However, moving learners from capability to ability requires several things [9, 24, 36]. 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.

3. 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 [11]. 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 as they design and implement their games, 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 [19]. 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 serving 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 [11, 30] by using a system of scaffolds [24, 36]. 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 [24, 36]. 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.

The Design Notebook's organization (i.e., the ordering of the pages) follow the phases of the game design described above (tool sequencing). Each Design Notebook page leverages two or more additional components of the system of scaffolds, depending on the task and the needs of learners. For example, the My Visualization – Pre-Physical Prototype Design Notebook Page (Figure 2) scaffolds students through articulating the core gameplay mechanic or the actions a player repeats most often while trying to play a game and then visually representing that core gameplay mechanic by describing the settings or places in which play happens, the activities players engage in when in those settings, and the things that are measured or acquired by the player during game play. This visualization activity helps Scholars understand not only what they need to build in their physical prototype foundations, but it also supports them as they understand and describe how the world systems, player activities, and rewards/metrics interact during gameplay. As Figure 2 shows, the My Visualization – Pre-Physical Prototype Design Notebook Page uses prompts, hints, and a template to help Scholars organize their ideas about the world systems, player activities, and rewards and metrics.



My Visualization – Pre-Physical Prototype

Group Name______________________

Core gameplay mechanic – Describe the actions a player repeats most often while trying to reach the goal in your game

World Systems	**Player Activities**	**Rewards/Metrics**
Hint: List the settings or places in your game where players can go	Hint: List the types of things players can do when they play your game	Hint: List the things that are measured (e.g., score) or the things that players can earn while they play your game

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 [38, 33, 24, 36, 27]. 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 [14, 19, 33, 8, 39, 7, 5].

4. METHOD

This section presents the setting, participants, data collected, and approaches for data analysis. We are in the midst of completing full data analysis for Season 1 data. While we are still collecting Season 2 data, we have begun preliminary analysis of some season 2 data, which will be described below.

4.1 Setting and Participants

This longitudinal between-groups study takes place at a Spelman College in Atlanta, GA and various locations around the metro-Atlanta area. Spelman College is a private, liberal arts, Historically Black College (HBCU) for women. Spelman College has been a leader in training minorities and women in Science, Technology, Engineering, Mathematics, and Computer Science (STEM+CS) areas, with about one-third of the students majoring in these fields. Currently at Spelman College, 97% of the students are African-American, of whom approximately 35% are majoring in STEM+CS fields. To date, we have worked with 23 African-American girls: 20 during SCAT Season 1 (their 6th grade year) and 20 during SCAT Season 2 (currently their 7th grade year). Each season, Scholars participate in the three activities described earlier: two-week summer camp, twelve workshops, and field trips. SCAT Season 1 ran from July 2013 – May 2014, and SCAT Season 2 started in June 2014 and will continue through May 2015.

4.2 Data Collection

We have collected and continue to collect various data including Scholar artifacts (Design Notebooks, storyboards, design documents, physical prototypes, software prototypes, presentations, etc.), video observations (both whole class and small group), semi-structured interviews, pre- and post-surveys (of students and parents), online journal data, and end of season online evaluation (questionnaire). While we are beginning to analyze all of these different data for Season 1, this paper will focus mainly on early insights suggested from some video observations (particularly whole class), some Scholar artifacts (i.e., storyboards, software prototypes), and end of season online evaluations.

4.3 Data Analysis

For the video observations, we examined and documented the enactment, as Scholars moved through the game design cycle, to identify and understand the phases that were carried out both during the summer camps (Season 1 and Season 2) as well as the workshops (all of Season 1 and six done so far for Season 2). We also examined whole class discussions to understand how the facilitator supported Scholars' understanding of their game design experiences as a whole and the impact it had on whole group discussions.

We analyzed Scholar artifacts, particularly storyboards and the functional SCRATCH games. Given that the storyboard is the first representation (visual representation) of algorithms in Scholars' games, we compared the set of storyboards for Scholar games created during Season 1 and the set of storyboards created for games during Season 2. In particular, we examined the following: both the length of the storyboards; the amount of and quality of visual detail depicted in the storyboards, which describe how the player moves through the game from beginning to end; and the complexity of the storyboards as the player plays the game. In addition, we compared the SCRATCH code generated by Scholars for the full set of Scholar games across Season 1 and Season 2 (Scholars are still implementing their Season 2 games) to understand if an increase in the length and complexity of storyboards translated to an increase in the complexity of the representation of the algorithms in SCRATCH (i.e., the combination of blocks in SCRATCH as well as the number of distinct blocks).

Finally, we engaged in preliminary analysis of the online end of Season evaluation data. This data, in the form of a questionnaire, asked Scholars to respond to the following: *Describe the game that you and your partner created. Please include details about how to play the game, characters, levels, etc., What do you think an algorithm is? What kinds of algorithms did you create in your game? What other kinds of algorithms can you think of that you designed, implemented, or analyzed during your SCAT experience (if any)? If you had additional time to change aspects or add on to your game, what would you do? What do you think computational algorithmic thinking is? Describe what you like and dislike about game design. Be sure to include both what you like and what you dislike. Do you see yourself as a game designer? Why or why not? How did you feel about using SCRATCH? What did you like and dislike? Describe your feelings about your SCAT experience (game design summer camp, workshops, field trip(s), etc.).* Our analysis focused specifically on the last prompt where we asked Scholars to describe their feelings about their SCAT experience. We wanted to understand what Scholars thought about their experience at the end of Season 1, including whether it was meaningful, whether they felt they were benefitting from the program, and in what ways.

5. FINDINGS

Although analysis of the full set of Season 1 data is on-going and we are still collecting Season 2 data, our analysis to date has uncovered findings that are quite promising and intriguing for the research and the program in light of the fact that we will continue to work with these Scholars for the remainder of Season 2 and into Season 3 (June 2015 – May 2016).

5.1 Game Design as a Context for CAT Development

Data suggests that game design is an engaging context for this population. While 95% of the Scholars (i.e., 19 out of 20) had never designed a game nor used SCRATCH prior to this experience, the Scholars did seem extremely engaged during the first SCAT Season. In fact, we have had an 85% retention rate across SCAT Seasons 1 and 2. While we did lose three Scholars from Season 1 into Season 2, two of the three Scholars expressed the desire to stay, but stated that distance (moving out of the state) and schedules would not allow them to continue to participate. It must be noted that the Scholar that moved out of state during Season 1 did continue traveling 1.5 hours each way for quite some time before she had to withdraw.

5.2 Decrease in Movement Through the Game Design Cycle

During the two-week summer camp held at the beginning of Season 1, the Scholars, working in dyads, were able to move through only the first three phases of the game design cycle: Brainstorming, Storyboarding, and Physical Prototyping. This movement through the game design cycle was expected because none of the Scholars had ever engaged in game design prior to this experience and because game design is an iterative activity that takes time if it is done well. The Scholar dyads spent the rest of the season (September 2013 – May 2014) iteratively implementing their games in SCRATCH and playtesting them with their peers.

During the summer camp at the beginning of Season 2, we expected that Scholars would move into the beginning of the Implementation phase, not only because 85% of the Scholars were returning Scholars and had already experienced the game design cycle during SCAT Season 1, but also because those same Scholars also had a great deal of familiarity using SCRATCH, though some review was required (e.g., how to create a scrolling background, how to add a timer, how to keep score, etc.). However, each Scholar dyad was able to move through all of the phases (including Design Document and Implementation) and completely implement the first level of their games in SCRATCH by the end of the two-week summer camp. As a result, dyads were able to accomplish in two weeks what took them eleven months to accomplish the previous Season. We expect that continued analysis will reveal what about the SCAT experience were critical factors resulting in this phenomenon.

5.3 Increase in the Complexity of Game Designs

While Scholar dyads were able to design and implement their games more quickly from Season 1 to Season 2 summer camp, we noticed an increase in the complexity of the design of those games. Scholar dyads created longer storyboards, describing more detail about the gameplay during the Season 2 summer camp than they had during the Season 1 summer camp. In fact, storyboards, on average, were twice as long, moving from 9 stills depicting gameplay to 15 – 18 stills depicting gameplay. We also noticed that the game designs involve more complex user interactions with the game, which required more complex algorithms to implement those user actions and resulting gameplay behaviors in SCRATCH.

5.4 Some Internalization of the Game Design Cycle

During the Season 1 summer camp, the game design cycle was presented and drawn on a whiteboard at the front of the room. It stayed there during the entire summer camp, and as Scholars moved from phase to phase, the drawing of the game design cycle was referenced and discussed. Once Scholar dyads moved into total implementation (which began around January 2014), the drawing of the game design cycle from the whiteboard, while referred to during discussion, was erased from the whiteboard and was not the persistent fixture on the whiteboard that it was during the summer camp.

However, during the end-of-season online evaluation given at the end of Season 1 (four months after the erasing the game design cycle from the whiteboard), three Scholars described the game design cycle in their open responses. Further, on the first day of the summer camp for Season 2, which was five months after the erasure of the game design cycle, Scholars were able to recall and recreate the game design cycle on the whiteboard as a part of a whole group discussion with the facilitator.

5.5 Scholars' Perspectives of Themselves as Game Designers

Throughout Season 1, Scholars learned a lot about not only game design, but also about the practices of game designers. The facilitator often mentioned that the activities they were engaging in were the same as game designers and that they themselves were game designers. However, the end of season evaluation responses suggested that most Scholars did not see themselves as game designers. Scholars seemed to suggest that seeing themselves as game designers implied that they wanted to pursue game design as a career. Examples of responses include:

- "…because I just don't think it is the career I want to have…"
- "I don't see myself as a game designer because I am not a gamer. I am really not into computer games to the point where I want to design them"
- "I do like how we made the games, but I don't like all the time it took up and that we had to keep redoing everything and have a lot of patience as we were working on a website with a lot of glitches [SCRATCH]. I also did not like the things we were using don't have some of the exact ideas that we had discussed over the summer camp. So, we had to morph our ideas to fit the computer preferences."
- "I'm not into making games – I would rather play someone else's games and give them feedback on it"
- "I don't see myself as a game designer. Now don't get me wrong game designing is an awesome thing to do, but if I did have a job as game designing it would be an on the side job."

Many Scholars suggested that, while they thought that game design was fun, at this point in their lives, they viewed game design more as a fun hobby than a future career.

5.6 Scholars Find Their Experience Meaningful

Despite Scholars not seeing themselves as pursuing game design as a career, they did express that they have enjoyed their SCAT experience so far, and that they feel they have gained a lot from the experience. Example responses include:

- "I think that SCAT is [a] really fun and challenging program. I am very glad I joined because it teaches you more about video game designing and how to think through problems."
- "Last years summer camp really helped me get started thinking about how awesome and educational it would be learning about coding, objectives, etc."
- "I really enjoy doing the SCAT program. I liked making the models and doing the field trips."
- "SCAT has been a good experience for me in everyday life. I have known more now than ever from this program."
- "I liked SCAT because it gave me a learning experience and it also gave me [a] chance to meet new friends."

6. DISCUSSION AND FUTURE WORK

The insights gleaned from early analysis of the data suggest that the SCAT project is having a positive impact on the Scholars and helping them develop their CAT capabilities. While on-going analysis will reveal more about how Scholars' CAT capabilities are developing and the impact of the SCAT learning environment and experience on that development, our findings to date suggest a positive impact for the program and the Scholars themselves. We will continue our analysis of the full set of data from Season 2, collect Season 3 data, and disseminate additional findings as they are revealed.

7. ACKNOWLEDGMENTS

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