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DESIGNING ANALOG GAMES THAT ENGAGE GIRLS WITH COMPUTER SCIENCE CONCEPTS

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This design case describes the development of three analog games intended to introduce middle school-age girls to core computer science (CS) concepts. We describe the learning objectives, game mechanics, and narrative elements of each game, and some key problems and decisions that we confronted during the design process. Our design process was guided by two key goals and assumptions: (a) the games should help players develop a *situated* understanding of CS concepts through engaging them in computational thinking (CT) practices associated with each concept, and (b) game mechanics and story elements should be meaningfully integrated with and supportive of the games' learning objectives. We discuss several challenges that we encountered in the design process, both in identifying CT practices that lent themselves to game mechanics, and in finding ways to embed mechanics into stories in a meaningful way. Data from gameplay sessions suggests that, on the whole, girls found the games engaging and improved their understanding of CS concepts. However, we conclude that we were only partially successful in achieving our design goals. Testing the facilitator guides with a broader set of users and integrating the facilitator role into gameplay and story are potential goals for future work.

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INTRODUCTION

Many initiatives are underway to broaden the participation of youth traditionally underrepresented in computer science (CS) courses and careers. These initiatives range from introducing children to simplified programming languages to integrating computational thinking across the curriculum (Barr & Stephenson, 2011). Digital games are a popular way to introduce young people to computer science, in particular to the basics of computer programming (Harteveld et al., 2014). This focus on coding, however, does not take advantage of games' potential to provide experiences that promote understanding of a wider range of foundational CS concepts and applications. The games described in this design case were developed as part of a larger effort to create a story-based digital game that would introduce a variety of CS *concepts* in a situated way. In this project, we created three analog games as a first step in exploring possible storylines, game mechanics, and CS concepts. Influenced by literature which suggests that story in games could be a motivating factor for girls in particular, (AAUW, 2000) we sought to understand if story made a difference in learning and engagement by creating different versions of each game: one version with an explicit storyline, one with story context only (i.e., a setting and characters, but

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no sequence of events), and a third version consisting of abstract concept-based puzzles alone. In this design case, we focus on the games with explicit storylines; the process of creating different versions of the games, and some issues we encountered, are described elsewhere (e.g., Gee et al., 2017).

Learning Context and Target Users

This design project was funded by the National Science Foundation's Advancing Informal Science Learning program, and the games were intended to be used in settings such as after school programs, libraries, or science centers. This intended context of use influenced the design of the games, as well as the creation of detailed support materials for facilitators, since we could not assume that facilitators would have backgrounds in computer science. Because learning activities in such settings tend to take place in limited time frames, we designed the games to be introduced and played in 2 hours or less, with the potential to be divided up into "levels" or rounds for more flexibility.

Consistent with common goals for informal science learning activities, we intended that the games serve primarily as preparation for future learning in CS, by increasing players' familiarity with core concepts and enhancing their understanding through applying these concepts in "real-life" problem-solving situations. Our primary target group for the games was middle school-age girls, particularly from lower socioeconomic backgrounds, with little to no prior exposure to CS concepts. This target group is underrepresented in formal CS educational programs and has been a particular focus for recent efforts to broaden participation in CS. Our game-based learning approach was informed by previous work suggesting the general appeal and benefits of active, hands-on CS learning experiences for all learners, but in particular for girls from underrepresented groups, who might be more likely to find traditional CS learning activities to be irrelevant or uninteresting (Ashcraft, Eger, & Friend, 2012).

Game Design Team

The team members involved in the game development process were all women, including two university faculty members, one in computer science (CS) and one in education, a PhD student in CS, a PhD student in education, and a professional game designer and author of educational games and stories for children and teens. The CS professor and PhD student had considerable experience teaching introductory CS with college students as well as secondary age students and played a primary role in identifying the concepts that would be the focus of our games. They worked closely with the game designer to identify game mechanics aligned with the concepts. The designer had recently worked on an interactive, multimodal story project aimed at a similar target audience, and that experience influenced her approach to the design of these games. The education faculty member and Ph.D. student had the most extensive experience with game-based learning, and they provided feedback on the initial game design documents, as well as the content of the facilitator guides. We also sought input from another professional educational game designer, as well as a university CS professor and his research team whose academic interests focused on narrative strategies in games.

Design Goals and Assumptions

Along with widespread efforts to teach young people how to code as a new "basic skill," there has been a growing interest in promoting an understanding of computer science (CS) concepts. A focus on CS concepts is often associated with computational thinking (CT), generally defined as a problem-solving process with attributes such as logically sequencing data or using a series of ordered steps (Barr & Stephenson, 2011). CS concepts inform this problem-solving approach, though CT can be applied to problems and tasks across many domains, making it possible to create learning activities that introduce CT and CS concepts in a variety of real-life contexts. This perspective formed the basis for one of the goals that guided our design process:

> The games should help players develop a *situated* understanding of CS concepts through engaging them in computational thinking practices associated with each concept.

Just as importantly, the design team shared the belief that well-designed educational games do not treat gameplay or narrative simply as a means of making learning "fun" or as a reward for mastering otherwise boring or irrelevant content. A second guiding principle, or goal, was:

> Game mechanics and story elements should be meaningfully integrated with and supportive of the games' learning objectives.

Our design process also was informed by our assumptions about what middle school-age girls would find appealing in storylines and forms of gameplay. Our interest in story-driven games was prompted by earlier studies indicating that narratives might make CS topics more appealing to girls (AAUW, 2000), as well as to achieve our general goal of making CS concepts more meaningful. Prior research also suggested the potential value of introducing girls to ways that computational skills and computing might help address relevant social problems (Ashcraft, Eger, & Friend, 2012), and story offered a way to illustrate such potential applications.

THE GAMES AND OUR DESIGN PROCESS

Origins of the Designs

We used several sources as a starting point for our initial conception of the games, including their learning objectives and important design features. We drew on the College

Board's Advanced Placement (AP) CS Principles curriculum framework (College Board, 2017) to identify the central concepts that would be the focus of the games. The framework consists of seven big ideas, each with a set of essential questions, enduring understandings, learning objectives, and knowledge statements. This framework is quite expansive, and we also consulted other CS frameworks and curricula to help in narrowing our focus. A particularly useful resource was *CS Unplugged* (Bell et al., 2010), a collection of non-digital learning activities that address discrete ideas associated with general topics such as Data, Algorithms, and Procedures. Initially, we selected algorithms, data representation with a focus on images, data organization and search, and abstraction as the broad concepts to be addressed in the games. We chose these concepts in part because they are fundamental to many everyday tasks, as well as essential to "thinking like a computer scientist." In selecting these concepts, we also relied on the following criteria: (a) Can aspects of the concept be taught in an age-appropriate way? (b) Is the concept general enough to be understood by a student with no prior computer science training? and (c) Does the concept have the potential to be explicated through a game? Early in the design process, we dropped Abstraction, due to our difficulties in generating ideas for gameplay reflective of this concept. As we will describe in the next sections, in the course of designing the games, we had to create narrower learning objectives associated with each concept.

The team drew on existing literature, analyses of existing STEM games conducted by members of our design team, and focus groups with middle school-age girls to identify game mechanics and storylines that might be appealing to our target group. In particular, we identified the potential appeal of storylines in which players could play active roles in addressing social problems or helping others, and that involved both collaboration and competition. We deliberately avoided storylines that involved stereotypical roles or themes for this group, such as romance or fashion.

Key Game Elements & Design Decisions

In the following sections, we describe each game and key decisions involved in their creation, including our original ideas for the game mechanic and story, and how these ideas evolved through prototyping and user testing.

Complete versions of the games were playtested in four different afterschool settings with 65 middle school-age girls from varied socioeconomic backgrounds. Most of the playtesting took place after school in middle school classrooms or school libraries, which made it easier to recruit participants from the target population. The play sessions typically lasted between 45–90 minutes. Facilitators deliberately created a relaxed, informal environment by providing snacks, breaks, and interacting playfully with participants. We video-recorded all sessions and took notes on gameplay.

Algorithm Relay Race

The Game. The Algorithm Relay Race introduces players to the idea of an algorithm—a series of very clear and precise directions for how to complete a task or solve a problem step by step. The primary learning objective of the game is that players come to understand that clarity and precision are central to algorithms that "work," and that they learn to break down tasks into discrete actions. The players work in teams, ideally composed of four players, to complete tasks that will help them find a lost cat. These tasks require the teams to split into pairs to write instructions, described as algorithms in the game, which their other teammates will later perform.

The game's narrative is based on a true story of Colins, a cat who lived at a New Zealand seaport and became an inadvertent stowaway on a South Korean tanker. The tasks in the relay race are based on locations and key events in the effort to locate Colins and return her home. The game facilitator reads parts of the story and uses props (such as pictures of Colins) to provide the narrative that gives meaning to the game tasks. The story includes the discovery of Colins on the tanker, efforts to locate and retrieve her before the tanker reaches South Korea, and the final safe return of Colins to her owner—a dock worker at the New Zealand port where Colins became famous as an international "ambassador."

Before the start of the game, the facilitator introduces the concept of algorithms and leads the group through an example. The game itself is played in two different stages, each involving two tasks. Players are given a separate clue bag for each task with instructions for writing the algorithm. In the first stage, one pair of players on each team writes an algorithm for the first task, placing Colins' food bowl and toys, to lure her from hiding (assuming she might still be on the dock). For this task, as an example, the clue bag includes a photo of the desired placement of these objects (see Figure 1). Simultaneously, a second pair writes an algorithm for the second task, plotting the tanker's route, identifying stops where Colins might have left the ship. The pairs then attempt to follow the other pair's algorithm, starting with the first task. Pairs are allowed to rewrite their algorithms if necessary. In the second stage, one pair writes an algorithm for the third task, decorating a crate that will be used to return Colins home. The second pair writes an algorithm for the fourth task, finding the cat (a toy cat or photo hidden in the gameplay space) and return with her to the final destination. Again, the pairs attempt to follow the other pair's algorithm, starting with the third task. Pairs are allowed to rewrite their algorithms if necessary. The first team to return with the cat to the final destination is deemed the winner.

FIGURE 1. Algorithm Relay Race. Sample image for Task 1, placing cat bowl and toys.

The game narrative evolved throughout the design process, as well. During our early brainstorming sessions, the team decided that the ultimate goal of the game would be finding a lost cat, reflecting our effort to create storylines that would involve players in helping others, and the assumption that our target group of girls would find cats particularly appealing. The original game premise was: "One evening, a very loved and intelligent cat named Hopper escapes the Grace family home through an open window and takes the entire animal rescue squad (the group) on a wild ride to find her." During our design work, a team member found online news articles about a stowaway cat that became the basis for the final game's narrative. The story of Colins, in addition to the appeal of a "real-life" situation, also had the benefit of adding a more exotic location and a dramatic, though not permanent, consequence of failure (the real-life Colins would have been quarantined for six months if she was taken off the ship in South Korea). This choice, however, meant that we gave up the possibility of a more flexible narrative, in which players might have looked for the cat in different places in different sequences by randomly drawing clue cards, an option we briefly discussed.

Key Design Problems and Decisions. The initial idea for the algorithm game was generated through the design team's early brainstorming sessions. Algorithms are commonly described to beginning CS students as step-by-step instructions, and often students are introduced to the importance of clarity and specificity in algorithms by asking them to write and then follow instructions for a common task, such as making a sandwich or tying shoelaces. With the goals of promoting teamwork and actively engaging players, our game was conceived as a "treasure hunt relay race." In our initial design, Player 1 wrote instructions for finding a hidden object along with a clue about the next object to find. One player from each team attempted to follow the instructions, and the first player to find the clue wrote directions to the next object and clue, and so forth. Teams could earn points for the accuracy of their written directions and their speed in locating the next hidden object. While the basic game mechanic did not change over the course of our design process, a key problem in the original design was keeping all players engaged throughout the game, particularly when one player was writing the instructions. This became apparent in prototype testing, when the players who were not writing got distracted and otherwise began to lose interest in the game. We addressed this issue in several ways: by having pairs collaborate on writing the instructions, asking them to pay close attention to how other players interpreted their instructions (so they could rewrite if needed), and having different pairs write instructions for two tasks simultaneously. The latter strategy was somewhat at odds with the linear nature of the final story, and that issue persists in the final version of the game.

Playtesting of the game suggested that the general topic of the story—a missing cat—was appealing to girls, though the girls' attention to the storyline waivered. In general, participants were initially engaged by the story of Collins, the cat, listening intently to the introduction and eagerly expressing their affection for cats or other pets in their own lives. They also seemed excited by the idea of a competitive relay race. Of the three games, the Algorithm game involved the most varied physical activity; players had to manipulate objects when placing cat toys or setting up the cat crate, and they moved around the space to find the cat in the final game round. We used a "write instructions for making a peanut butter and jelly sandwich" activity to introduce the need for precision in writing algorithms, which led to plenty of laughter as the girls discovered flaws in the instructions they created.

During the initial gameplay tasks (writing instructions for placing the food bowl and completing the map), some teams became confused about what they were supposed to do, and the facilitators played an important role in clarifying the instructions for individual groups. Eventually, the girls moved from quiet talk in small groups as they discussed each task to more lively conversations about the best way to write up their instructions. During the wait time, as various groups finished writing their instructions before others, some girls chatted about their pets or doodled cat drawings on scrap paper, an additional indication of their interest in the topic, if not the story itself.

In all cases, the groups that wrote the algorithms had difficulty not "helping" when they observed their teammates begin to follow the algorithms incorrectly, or when errors in their algorithms became apparent. The facilitators had to step in and admonish the authoring pair not to tell the other pair what to do. In most of our field tests, the girls completed the full game in two separate sessions. By the second session, the girls' algorithms improved, and the pairs cooperated more effectively in the tasks of writing and following the algorithms. The girls tended to be very excited about the final task of hiding and finding the cat, and that created a higher energy level in this session than in others. While the girls enjoyed the chance to get away from the meeting room and walk (or often, run) down corridors and to other spaces, the activity became difficult to supervise; sometimes a pair of girls would take off to look for the cat without giving enough attention to the instructions written by their team members.

At the end of the game, the facilitators gathered the girls together to conclude the story, telling them that Collins was returned to her owner in the decorated crate of the winning team, and the airlines flew them home to New Zealand for free. Some girls seemed to forget that this was a true story, but there were cheers and smiles over the happy ending. In general, interest in the storyline seemed to dip during gameplay, when the girls became more focused on the game mechanics, but peaked again at the end, with the story providing a satisfying resolution to the game.

One issue in the game that became apparent in play-testing sessions was the variable difficulty level of each task. The team created tasks that aligned with the story and did not consider factors such as how many steps it might take to complete a task, or other abilities required to be successful, including basic writing abilities or spatial awareness. Besides, we intended for the tasks in this game to be customized by the game facilitators, who might use their own set of pet toys and desired arrangement for Task 1, for example, or use a more complex set of decorations for the crate in Task 2. Whether the complexity of the task affects players' general understanding of algorithms remains an unanswered question concerning the game's outcomes. However, we do feel that modifying the tasks, so their complexity gradually increases might be more motivating for players, by giving them an early experience of success and a more explicit feeling of increasing mastery.

The Hidden Image Game

The Game. The Image Representation game, or "Hidden Image Game," was designed to teach players about representing data in different ways, including encoding and decoding data. It is similar to *Battleship* in that it is a two-player game in which each player has before her a blank grid, and each of the squares on the grid is referred to by a pair of coordinates.

In the story version of the game, players take on the role of aid workers who are assisting Syrian refugees in fleeing from a war zone. In order to help them get to safety, aid workers must send and receive messages which are encoded to ensure that the transmission remains secure.

Each player's goal is to fill in squares on a blank grid and reveal a hidden image. Each player has her own blank grid, and another grid which is filled in with the image her opponent is trying to uncover. Players take turns by naming a pair of coordinates, and the opposing player states whether the square at those coordinates is black or white. If it is black, the player fills in the square, and she gets to call out another pair of coordinates. If the square is white, her turn is over.

If she calls out a previously uncovered square, and the squares to the right of it are the same color, she gets to fill in every square of that color in the row until the color changes. So, if she calls out 1,5, a previously revealed black square, and all of the squares next to it are also black, she can fill in all of those squares until the end of the row. This mechanic is designed to teach the concept of run encoding.

After players have completed this part of the game, other protocols for encoding are introduced, and players practice these protocols together. Finally, players work together to encode data; that is, to represent images as numbers. In pairs, players work together to encode data written by the facilitator as quickly as possible to generate "passcodes." The most accurate pair of players wins the game.

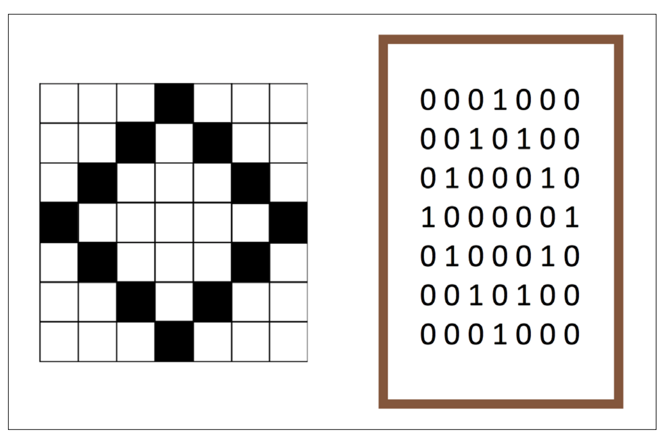

FIGURE 2. Hidden Image Game: Sample Image and Code.

Key Design Problems and Decisions. The Hidden Image Game went through a number of iterations before its final version. While the idea of refugees and hidden information came up in early discussions, it wasn't associated with the game's mechanics. It later re-emerged, along with discussions of a grid-style game with hidden information. The initial mechanic of this game was similar to *Minesweeper,* in which players try to avoid uncovering squares that contain mines. The game began to resemble its current version with the introduction of the idea of asymmetric gameplay, in which players had access to different information. This led to the final version of the game, in which players try to uncover various images. Our game designer, in particular, believed that revealing images and not abstract patterns would be particularly motivating for our target age group.

The question of whether the games, in general, could truly be considered games and not just activities was part of all of our discussions, but it was especially prevalent here. In earlier discussions, *Battleship*-style games were dismissed as not being fun or motivating, but it was still decided by the team that this was the best way to teach this particular concept. Questions as to whether this game was more of an activity continued throughout the design process, but early playtesting of the game revealed that it worked well and seemed engaging enough to merit further exploration. Although additions were discussed, such as a three-player version of the game, these were dropped in favor of keeping the game more streamlined.

Any concerns about the appeal of a *Battleship*-style game were quickly alleviated in play-testing. Similar to the approach used in the other games, the facilitator introduced the game narrative and player roles, and then led participants in a large group discussion of how information can be represented in different forms. As a warm-up activity, small groups of girls were given cards with images and codes and then had to figure out the encoding system to match each code with its corresponding image (see Figure 2). This activity generated a lot of excited talk, as most participants quickly began talking within their group, asking questions of the facilitators, and competing to be the first team to complete the matching game. This level of engagement continued, for the most part, through the rest of the game. The girls focused their attention primarily on their partners, as they named coordinates and filled out their grids. There was a low buzz of conversation throughout gameplay, with some cross-talk among pairs at the same table or with facilitators, along with the rustling of paper as the girls concealed their grids from their partners. Consistent with our game designer's belief, the girls reacted with pleasure when they identified the "hidden images." Since the images were comprised of squares on a grid, some girls had difficulty interpreting them, but on the whole the use of images seemed like a positive aspect of the game.

In field notes, facilitators expressed surprise at the girls' engagement and how well they seemed to grasp concepts like run encoding as they applied to the game. Most of the girls were familiar with *Battleship* and *Bingo*, and that familiarity seemed to make them feel more comfortable and confident about playing the game. In contrast to the Algorithm Relay Race, the Hidden Image game introduced new ideas associated with the overarching concept in a sequential way, and this seemed to hold the girls' interest and give them a sense of mastery as they completed each level. Some girls became confused by the instructions and grids for the last level of the game, and by the switch from decoding to encoding an image. The facilitators had to spend more time clarifying the instructions than in previous levels. However, during gameplay, in which girls had to write lines of code within strict time limits, there was palpable excitement, with low cries of "go, go, go" as partners encouraged each other and groans when they didn't complete the encoding. All in all, playtesting suggested that the game mechanic was effective in engaging the girls and in illustrating the computer science concept.

The game story, similar to the Algorithm game storyline, was initially interesting to participants but was sidelined as they focused on the game mechanics. When it became apparent that some girls did not fully understand what it meant to be a refugee, facilitators brought in photos and news stories about current refugee situations. The facilitators reintroduced aspects of the story throughout gameplay; for example, in the third level, facilitators explained the need for accuracy and speed by explaining that the girls would be encoding the password for refugees to use in order to be allowed into a safe house. In general, while the girls seemed excited by the idea that they were going to learn how to encode and decode "secret messages," the story narrative as a whole did not appear to play much of a role in their engagement with the game. Even the ending, in which the girls were told they had helped refugee families enter a safe house, was received with only mild interest. We speculated that focusing the story on a specific refugee family (similar to how the Algorithm game focused on a particular cat) might make it more compelling, and that is a potential change we will explore in future implementations.

Villain Search: A Global Quest to Save Wildlife

The Game. One very common computer application is storing and retrieving information. *Villain Search* introduces players to the value of sorting data to locate an item, and to the idea that different methods of organizing data are appropriate for different situations. In particular, the game gives players the opportunity to compare the effectiveness of a linear versus binary search strategy for numerical data, and to explore other ways of organizing data (i.e., by category) to facilitate the search process. *Villain Search* is a

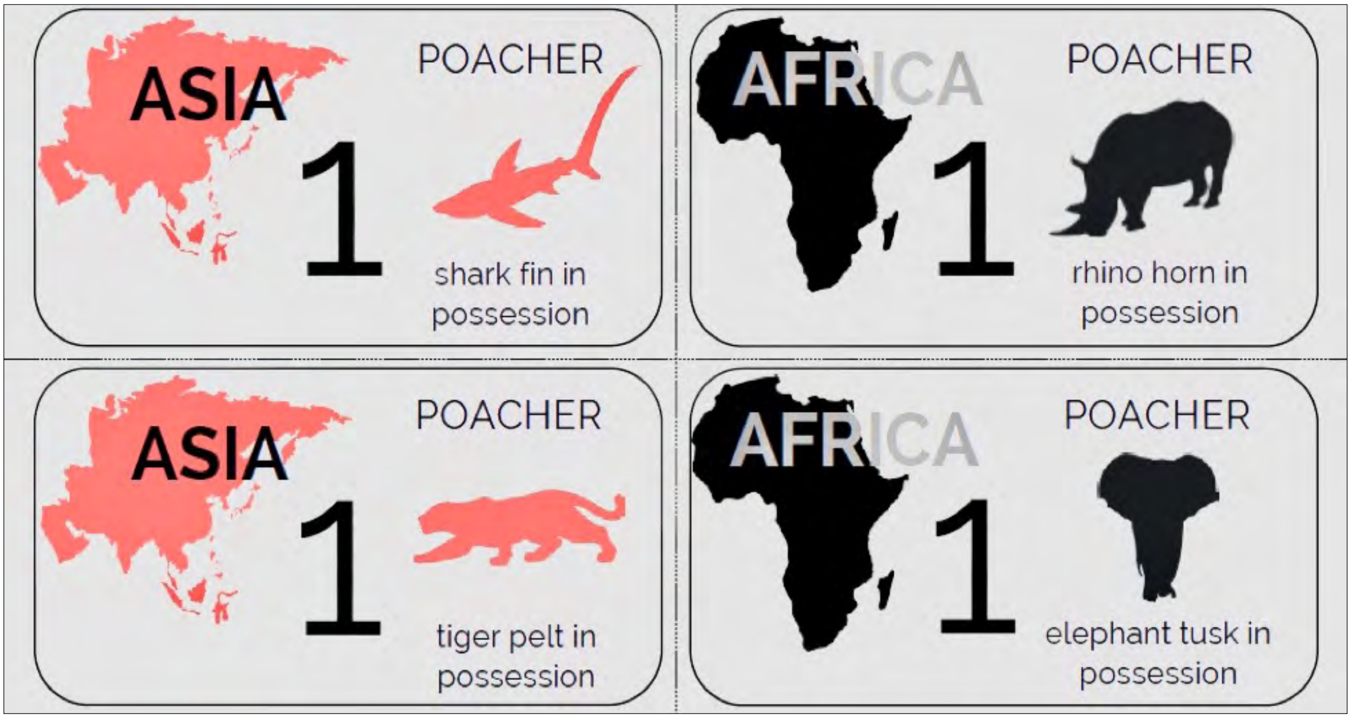

FIGURE 3. Villain Search: Sample Data Cards.

card game for two or more players. The goal of the game is to search for one target card from among a set of data cards. A deck of data cards is placed in one group face up in front of the players. Each player draws a different target card from a second identical deck of data cards, which is set aside. Players take turns choosing action cards that allow them to sort the deck of data cards into smaller groups, with the goal of isolating their target card to win.

The game's story puts players in the role of wildlife agents who are on a mission to track down poachers and sellers of four endangered species of wildlife across three continents. A deck of data cards is comprised of 52 cards, each with a number from 1–13, a poached item (elephant tusk, rhino horn, shark fin, or tiger pelt), continent (Africa or Asia), color (red or black), and villain (poacher or seller). Players' target cards are drawn from this data card deck, and thus each player has a somewhat different set of parameters that will yield the most productive grouping of cards. There are multiple copies of 10 different cards in a separate action card deck, each allowing the player to use a different sorting strategy. One card, for example, states: "Remove 2 or more cards from two piles and form them into a new pile. All the cards in the new pile must have a common category." As players take turns using action cards to sort the data cards, they begin to understand what actions will help them isolate their target cards more quickly. Players do not know each other's target cards, and a player may unintentionally separate out the target card of another player, who can claim it and win at her next turn.

Key Design Problems and Decisions. Our team found this game to be the most challenging to create. The first challenge was to identify a narrative context for the game that would offer a plausible reason for using different ways of organizing and searching data, particularly binary searches. We identified four preliminary contexts, which were searching for lost laundry, determining the source of an epidemic, searching for one book among many, and searching for one particular bead from within a mix, with players assuming the role of a protagonist who needs to accomplish a task. Given our assumption that using narratives based on social issues would appeal to our target population, we spend a number of weeks trying to figure out how to use the context of a global epidemic for the game but could not find a satisfactory way to integrate the desired forms of data organization and searching. Finally, inspired by a discussion of the card game *Guillotine*, the game designer proposed that the search should focus on finding modern-day villains, and retain a global setting to be consistent with our other games. Endangered wildlife was a topic currently in the news, and we felt that protecting animals might again be particularly appealing for our target group. For the final version of the game, we developed a cooperative book search for the pre-game introductory activities, and a "villain/wildlife search" for the final game, in which players must locate poachers of endangered wildlife and dealers of the poachers' products such as rhinoceros' horns and shark fins.

A second challenge was to create game conditions that would maintain the difficulty of real binary searches and eliminate the possibility of finding the target using simple yes/no questions. Using a card game seemed like a natural fit from the outset since cards can be readily sorted using various rules or strategies. As Figure 3 suggests, we used colors, numbers, and images for our data cards, and derived the idea of using action cards (to represent different sorting strategies) from games like *Guillotine*. Action cards would constrain the kinds of sorting techniques that players could use. We debated whether action cards should be chosen randomly (increasing the role of chance) or all provided at the outset (potentially more realistic in an actual computer programming situation). Through early pilot tests, we determined that giving players four action cards at a time provided an appropriate level of challenge; more cards were difficult for players to understand and use effectively, while too few made the game feel tedious.

In playtesting sessions, girls tended to express excitement about taking on the role of wildlife agents on a "special mission" to protect wildlife. Some girls were unfamiliar with the term poacher (for example, saying that this was someone who killed people) but others shared very specific information about the kinds of reasons poachers would hunt down animals like elephants. During the introduction to the game, the facilitator makes several changes in topic, moving from poaching to the nature of searching to the definition of "data," asking for participants' ideas about each subject. The changes in the topic seemed to keep the girls' attention, though transitions were often slowed down as the girls continued to chatter about the previous topic. The introductory book search activity also kept the girls engaged; they received sets of cards with book titles and other information, which typically prompted conversation about books they liked or disliked.

At the start of the Villain Search game itself, the facilitators remind participants of their role as wildlife agents, review the rules for the game, and do a brief demonstration of how action cards are used. It was clear that the girls did not really grasp the rules until they began to play the game in small groups. Facilitators played an important role in explaining the rules and helping the girls play through an initial round of the game. As a girl played each action card, the rest of her group tended to lean over to read the card and make sure that the action was performed correctly. In some cases, one member of a group continued to struggle with the rules, but the rest of her group stepped in to help out, suggesting what she should do in order to keep the game going. As the girls became more familiar with the action cards, they played more independently, and they began to take more time to choose cards to play. The play sessions were characterized by a continual level of talk, laughter, and groans, as the girls became more engaged in gameplay. The final level of the game is a "lightening round," in which players and groups compete to isolate their villains first. In the game narrative, this level is introduced as an opportunity for the wildlife agents to receive rewards donated by a multimillionaire, and the facilitators provide small prizes to the winning player and team. This element of competition along with prizes proved to be very motivating to participants, and the last round was characterized by a high level of excitement, with loud talk, joking, and intent focus on gameplay strategy.

Overall, playtesting suggested that the story was appealing to our target audience, and they enjoyed the game play. While it took a little time for them to master the rules, the girls did not seem overly frustrated, and most eventually became comfortable after a few games. Our main concern was that after a few rounds in the game, the girls were aware of where their target card was located, and they used that information to choose action cards, rather than basing their choice on the specific affordance of the sorting strategy. This limited the opportunities they had to become more aware of the benefits and drawbacks of different strategies. We became aware of this problem during the final implementation and were unable to design a solution.

CONTRIBUTIONS TO DESIGN KNOWLEDGE

In summary, in our playtesting over several implementations of the games in different afterschool settings, players reported that gameplay was engaging, and the majority showed improvement in our assessments of their understanding and application of each concept (see Gee et al., 2017). Here we reflect on the extent to which we achieved our design goals and other factors that affected our design decisions.

Did We Achieve Our Design Goals?

Our first design goal was that the games should help players develop a *situated* understanding of CS concepts through engaging them in computational thinking practices associated with each concept. This goal was central to our rationale for using games in the first place; we believed that games would offer concrete, memorable experiences that would lay the foundation for players' more general insight into, for example, why sorting information in different ways is helpful in locating a particular key target, or what happens when instructions are incomplete or unclear. Unlike some other educational game projects, where the goal is tied to more traditional academic learning objectives, such as mastering specific skills or content, we aimed at providing learners with a playful, introductory experience with the concepts. One issue that arose in our design work was how to choose what aspect of the CS concept to serve as the focus of each game. The CS concepts that we started with were obviously quite broad, and in typical CS curricula are associated with a variety of learning objectives. We struggled to achieve a balance between emphasizing strategies or ideas that corresponded to traditional CS curriculum and real-life applications that were not always so "clean" or discrete.

A related issue was the extent to which we explicitly introduced key terminology associated with each concept as part of the games or the overall experience. For example, how and when should we discuss the term "algorithms" in the Algorithm Relay Race, or explain the nature of a binary search vs. linear search strategy? To what extent would this turn the game into a didactic lesson rather than a playful experience? On the other hand, if a goal was to prepare the players for future learning associated with the concepts, wouldn't it be important that they identify what they do in the game as relevant to computer science?

The above issue was heightened by our choice of story settings. Similar to other approaches to introducing computational thinking, we did not put players in the role of computer scientists, or even in situations where computing was part of the story, where it would have made more sense for them to use CS terminology. Our resolution to this issue was to have the facilitator discuss key terms and provide (minimal) explicit information about the concepts as part of the introduction to each game. As we will describe below, we remain concerned that this more didactic facilitator role detracted from the playful nature of the game experience.

Our second design goal was to meaningfully integrate game mechanics and story elements with the games' learning objectives. A common critique of many educational games is that gameplay is used to motivate the learner to master content that has no real connection to the game or game world; for example, a player is rewarded for completing math problems by having the opportunity to shoot aliens, or she moves through a fantasy story world by completing arbitrary spelling exercises. Such approaches can veer towards gamification, with learners receiving points or other rewards for completing what are just academic exercises.

As our design process progressed, we realized the importance of making more explicit our assumptions about how game mechanic, story, and learning objectives might be "meaningfully" integrated. We spent the most time and energy on creating game mechanics that aligned with the concepts, and less time considering how the game story made the game mechanic and CS concept more meaningful. In broad terms, the game mechanic "made sense" in the story; for example, coding and decoding messages to assist refugees in navigating a secret escape route, or following instructions to locate a missing cat. The game tasks, however, were not realistic in the sense that, for example, you would not search for poachers by sorting cards, or decode secret messages by filling in squares on a grid. Game tasks do not, of course, need to be realistic to be entertaining, or even educational, but how closely aligned they need to be with "real world" application is, for us, a question that merits further consideration in the design of games for learning. Lastly, while we were aiming for the players to move through a clear storyline as they progressed through the games, none of the games really achieved this, partially due to the difficulty of imposing a linear narrative on a series of tasks that did not always directly fit with their respective stories. This did not seem to interfere with players' engagement with the games but raised questions for us about the desirability and feasibility of creating analog games of this sort with linear narratives.

Other Factors Influencing our Design Decisions

In addition to our design goals, a number of other factors played an important role in the final design of the games.

Computer Science Educators' Expertise

Two of our team members had considerable experience with teaching introductory computer science concepts, and their beliefs about what learners needed to know guided the process of narrowing down each concept to a particular set of objectives. Particularly important was their knowledge of what learners tended to find difficult, and what kinds of real-life examples might best correspond to these objectives.

Constraints of Designing Analog Games

For this project, we chose to design analog rather than digital games to reduce the time, cost, and complexity of game production. This choice created a number of design constraints, including the need to represent CS concepts in a non-digital context and to design games that involved player interactions (as opposed, for example, to player-computer interactions). These constraints were beneficial in prompting the team to think carefully about their design choices. In addition, the entire team could be involved in discussions of how to marry CS concepts with game mechanics and storylines without the added complexity of working with software programmers to create a playable game.

Players' Knowledge and Skills

We assumed that players' previous exposure to CS concepts would be the most relevant aspect of their prior knowledge affecting their engagement with the games. In our playtesting, however, we discovered that some girls had difficulties with spelling and grammar that affected their ability to write instructions in the Algorithm Relay Race, while others had trouble using the coordinate system in the Hidden Image game. Some girls also were unfamiliar with content from the games' storyline, prompting the game facilitators to deviate from the game script to provide, for example, some information about New Zealand's location and culture, what it means to be a refugee (in the Hidden Image game), or why someone would want to kill the animals in the Villain Search game. These issues reinforced the value of having a game facilitator who could provide additional information and support. They also pointed to ways that the games could be integrated with other subject area instruction, which is a goal of some computational thinking curricula (Grover & Pea, 2013).

The Facilitator's Role

In general, a game facilitator plays a crucial role in our game designs. As we noted above, the facilitator introduces key vocabulary and CT strategies, explains the game goals and rules, and narrates the game storylines. S/he also monitors gameplay, makes sure that players are following the game rules, and when necessary, decides what team or player is the winner. While we did not use this term in our design process, the facilitator could be viewed as part of the "metagame" or the out-of-game resources and environment that influence gameplay. Important products of our design process are the facilitator guides that spell out the facilitators' roles and provide detailed information about how to implement the games.

FUTURE DIRECTIONS

From the beginning of our design process, we anticipated that facilitator guides would be essential. However, we did not plan specifically for testing the facilitator guides with non-project team staff as facilitators, and this remains an important goal for our further work on the games. We have also begun to discuss the possibility of integrating the facilitator into the game story and gameplay, in these or similar games, in order to mitigate the didactic role the facilitator takes on in the games. This role could resemble that of the Dungeon Master in the *Dungeons and Dragons* role-playing game, who has a more active role in creating the storyline, describing the context, and arbitrating rules than in our current games. As another alternative, the facilitator could have an identity specific to the game, for example as the owner of Colins, who is conveying information to the search teams, or as the leader of the aid organization that is assisting refugees in the Hidden Image game. Our primary goal would be to enhance the sense of playfulness and immersion in the games and reduce the more "teacherly" aspects of the facilitators' current role. Such changes might also support our desire to find ways to better integrate story elements with gameplay and the learning objectives.

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