ABSTRACT

Computational thinking (CT) is increasingly seen as a core literacy skill for the modern world on par with the long-established skills of reading, writing, and arithmetic. To promote the learning of CT at a young age we capitalized on children’s interest in play. We designed RabBit EscApe, a board game that challenges children, ages 6-10, to orient tangible, magnetized manipulatives to complete or create paths. We also ran an informal study to investigate the effectiveness of the game in fostering children’s problem-solving capacity during collaborative game play. We used the results to inform our instructional interaction design that we think will better support the learning activities and help children hone the involved CT skills. Overall, we believe in the power of such games to challenge children to grow their understanding of CT in a focused and engaging activity.

Categories and Subject Descriptors
K.3.2 [Computer and Information Science Education]: Computer science education; K.3.1 [Computer Uses in Education]: Collaborative learning.

Keywords
Computational thinking; tangible games; education.

1. INTRODUCTION

Every generation of adults and parents tries to prepare their youth for a successful and happy adult life. The preparations we teach our children evolve with our societies. In today’s world of ever more pervasive technology, we consider technological skills and understanding of systems to be critical competencies for our children’s future. Computational Thinking (CT) is a current area of inquiry around what it takes for the 21st century citizen to function in an environment where interacting with technology is required for much more than work or recreation, but also to act on other necessities. To help produce future generations with these competencies, we believe that we should start teaching these concepts at a young age, and continue using a spiral curriculum [4] to reintroduce elements of CT in different subjects and different

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years. In order to be successful with children as young as age 6, and when repeatedly encountering these themes, it is important for the activities to be engaging, pedagogically sound, and well- (but not over-) structured.

The overarching goal is to equip children with the necessary problem-solving skills to cope with the abundance of challenges in our increasingly technologically demanding era. Being able to solve hard problems through computation is a considerable qualification for their future everyday and professional lives, as well as a “cognitive pillar” of literacy [7]. There are many opportunities in children’s lives for leveraging this type of thinking and helping them develop the necessary skills, which have recently been included under the umbrella of CT. Traditional games like Scrabble and chess are examples of appropriate vehicles for evoking the higher-order skills that are necessary for effective problem-solving [11].

Additionally, games are motivating for children and promote learning in an engaging and entertaining manner. We created a physical board game to underpin the skills and attitudes of CT. We argue that the game is a pedagogically sound sandbox for enabling children to engage in CT through collaborative problem-solving. We have taken into account previous work both in computer and tangible games and how they leverage the involved CT skills for successful game play. In the following sections, we present RabBit EscApe, an educational tangible board game that supports CT through collaborative game play.

2. RELATED WORK

2.1 Computational Thinking Pedagogy

Since Wing’s influential work [19], the research around Computational Thinking (CT) has exploded into myriad lines of divergent pursuits. Following prior work such as the Great Principles of Computing [6] on the topic of defining either prerequisites for computer science (CS) or its transferable skills, and coinciding with other work attempting to broaden participation in CS, Wing et al. have demonstrated the immensity of the research space around CT. Much of this work has offered working definitions of CT [1, 2, 5], but none has become the standard.

Despite the current diversity of views, various institutions have committed to agendas supportive of “computational thinking.” We chose the Operational Definition of Computational Thinking for K-12 Education by the International Society for Technology in Education (ISTE) [9] as our operational definition for this work. We thought this to be an appropriate definition due its relevance to our target group, but also its clarity regarding the expectations, skills, and attitudes involved. According to this definition, “CT is a problem-solving process that includes (but is not limited to) the following characteristics”: [details]

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• Formulating problems in a way that enables us to use a computer and other tools to help solve them
• Logically organizing and analyzing data
• Representing data through abstractions such as models and simulations
• Automating solutions through algorithmic thinking (a series of ordered steps)
• Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
• Generalizing and transferring this problem solving process to a wide variety of problems

In support of the aforementioned skills, ISTE suggests that students should be able to express five specific attitudes and dispositions, which are presented in the RabBit EscApe section discussing how our game satisfies each one of them.

2.2 Tangible Educational Games for CT

It is natural to want to extend the enthusiasm and promise of educational games to every domain; CT should be no exception. To offer an environment in which play and, hopefully, fun result in learning CT would be ideal. However, unlike many other domains, the definition and scope of CT is still in flux, making it challenging to argue (or at least to have agreement) that a given activity would support CT.

Indeed, based on the notion of learning by doing, researchers at MIT Media Laboratory have coined the term objects-to-think-with as a means to leverage the power of computation in the exploration process [13, 14]. LEGO/Logo is maybe the most famous offspring of this approach where students are learning to program by controlling enhanced LEGO structures (equipped with motors and sensors). Resnick et al. proposed "digital manipulatives" as a continuation of this work where students are called to control through Logo programming other tangible artifacts like blocks, balls, beads, and badges [13]. On the other hand, we were interested in investigating how low-cost games with easy to manufacture components can be leveraged to provide CT exposure to very young children (less than 10 years old).

Along these lines, Berland and Lee explored the CT that might be taught in the commercialized board game Pandemic [3]. As Pandemic is essentially a cooperative multiplayer game with a graph-theoretical representation of several major cities in the world, some implications of the involved CT concepts stem from the fact that the game mechanic is the opponent rather than the other human players. The aspects of CT the authors chose to focus on were conditional logic, distributed processing, debugging, simulation, and algorithm building. One of the things Berland and Lee propose in their work is that maybe board game designers should focus on intentionally designing their games as a means to encourage CT. We too think that there is great potential in exploring the challenges of instructional design in turning a tabletop game into a tool for developing computational thinking. This was our basic motivation for exploring existing board games and eventually developing our own.

3. RabBit EscApe

RabBit EscApe is a board game with tangible wooden pieces intended for ages 6 and up. As shown from previous work, tangible wooden blocks like the Froebel blocks [10] are engaging and educational for this age group, contributing to children’s emotion-
3.2.1 Collaborative

Players are given a predefined number of bits and a board and need to complete the board with all the pieces. Team players need to negotiate about path building, by collaboratively evaluating the board state and available bits. Distributed computation [17] is apparent when the players interpret the staged pieces and converse to construct a rule-based plan and complete the path. Distributed CT was also indicated as one of the distinguishing properties of CT compared to CS, according to the National Research Council [5].

3.2.2 Competitive

Players or teams are playing against each other and have to complete the most of the path but starting from opposite ends, working toward the middle. They roll the dice and can place as many bits as the number rolled. This activity demands well organized planning, since making the wrong choice will render the board impossible to complete. This competitive mode demands efficient modeling skills since opponents would need to simulate the construction of a large portion of the board with the available pieces, to avoid the cost of negotiating retraction of a previous block or bit placement. Both model building and simulation (forming and contrasting hypotheses) have been defined as foundational aspects of CT and revealed increased benefits compared to traditional methods of instruction [18].

3.2.3 Board Construction

With an entry point on one side of the board and finish on an exit point at another side, a team can use all the bits or a random subset and make a custom path on an empty board. They have to do this by drawing the blocks on the board but without placing the bits. They will need to create a mental model of the path, taking each “used” bit out before moving on, until they believe they have drawn the whole path. Another team can then use this custom board to play the game in either of the first two ways. Like the competitive activity, this construction method demands well organized planning to combine bit properties in order to make a playable board. Considering bits and their properties to be the data, players need to construct sets of pieces as part of the path using conditional logic during the process similarly to writing an algorithm (e.g. “If I place this bit here, then this block has a minus on the bottom and needs a big square piece with a plus on the top”). This activity in particular demands the complex skill of combining different requirements to build a set of steps that will lead to an efficient solution of a problem and has been defined as procedural or algorithmic thinking [12], considered a core concept of CT [5].

3.3 CT in RabBit EscApe

RabBit EscApe satisfies most of the characteristics of the Operational Definition of CT for K-12 Education as defined by the ISTE [9]. Considering the game mechanics and supported activities, students playing the game should be able to:

Logically organize and analyze data. Bits have to be organized in blocks and block combinations that are meaningful according to bit properties and the path’s form; pattern recognition is important in this process for identifying which bits create blocks that can fit the path printed on the board while also attracting adjacent blocks or repelling ape blocks (demands analyzing the board based on possible bit combinations and organizing them on the path).

Automate solutions through algorithmic thinking (a series of ordered steps). Board construction setup demands that players devise some kind of strategy for correctly utilizing bits and matching the polarity and magnet position; for this purpose they need to come up with some kind of “recipe” for putting bits together while drawing the path on the board, also accounting for the remaining pieces (demands some kind of procedural thinking).

Identify, analyze, and implement possible solutions with the goal of achieving the most efficient and effective combination of steps and resources. In all game setups, especially Collaborative and Competitive, players need to correctly identify the combination of blocks and bits by analyzing the path’s comprising shapes and then simulate possible solutions for effectively completing the board, with the least number of bits and in the minimum time (efficiency).

Additionally, the game supports all dispositions and attitudes that are essential dimensions of CT, as expressed by the definition:

• Confidence in dealing with complexity: Puzzles are inherently complex systems and without an operational strategy for dealing with complexity, the task might prove too challenging. RabBit EscApe introduces added complexity due to the additional puzzle piece properties that need to be accounted for. Confidence is built through successive iterations and attempts during the scaffolded activities, as discussed under the Discussion.

• Persistence in working with difficult problems: Deriving from the previous attitude, students are called to overcome initial frustration and persist in finding the solution. In our informal study (see: Discussion), two groups finished the game with one wrong bit placement, but still persevered to start over and get the whole path completed correctly.

• Tolerance for ambiguity: All three of the suggested activities include some degree of ambiguity deriving from either the complexity of the board and the amount of clues provided (e.g. including block divisions or a “cheat sheet”), or from the collaborative or competitive nature of the game (i.e. no two players have the same understanding about, nor expectations for the game).

• The ability to deal with open-ended problems: Being able to cultivate the previous attitude naturally leads to practicing their ability to deal with open-ended problems. Especially in Board Construction, players must have a good understanding of the game mechanics and bit properties, and be able to deal with the messy process of modeling a new path with minimal constraints.

• The ability to communicate and work with others to achieve a common goal or solution: All three modes of play have been designed to encourage or demand some form of collaboration or competition. This requires players to externalize their mental models and rectify any misconceptions. Even in the Competitive activity, students have to express their intentions through negotiations with the opponent(s), as a means to achieve their goals.

4. DISCUSSION

Although we did not have sufficient time to complete a rigorous evaluation of RabBit EscApe, we ran an informal study at an elementary school with two groups of three students each, aged between 8 and 10 years. We discovered that scaffolding is a necessary step in enabling children to get the most out of such a game. Scaffolding includes levels of increasing difficulty, starting from making a single block and moving on to more complicated shapes. At some points kids will have the option to construct the different shapes using more than one combination of bits, and will have to incrementally take into account other piece properties and examine the implications of their choices. This mental modeling of the different affordances of each piece will enable children to
be more efficient in the actual game activities, without demanding extra cognitive load to process them during gameplay.

Another idea to aid the bit selection and usage process is to provide a separate “cheat sheet” with all pieces and their count, next to the actual game boards. Players can cross out any pieces that have been used with a marker in order to keep track of what has been used and what is still available. This cheat sheet can be used during the initial sessions and then progressively removed, letting the users depend on their ability to recognize the physical pieces. This is a common process of scaffolding in instructional design, also called fading, because the additional information (scaffold) is removed (faded) over time [8].

These introductory puzzles can also assist in dealing with some observed instances of under-specification. We suggest that children should have a very clear understanding of the pieces properties and the constraints that they introduce. Thus, we should help them form some kind of algorithmic representation including all the properties that bits should have in any given position, and show them how to apply it in similar situations. This can be achieved through guiding questions that will lead children to evaluate the different properties of any missing piece on the board. Questions like “How big should this piece be?”, “How should it attach to adjacent blocks?”, and “What polarity should the magnets have?” will help them construct mental functions of bit and path properties that need to be evaluated at every point.

Social interactions are important in the conversion of the game attributes (i.e., path shape on board, bit properties, remaining bits) to mental functions. Students should be encouraged to question each other’s assumptions while moving from the initial introductory puzzles to more complex game boards, to prevent an adversarial tone. Because the game could become quite difficult, depending on the path and pieces provided, we found it helpful to include a “more knowledgeable other” in the form of a guide, who could intervene before frustration overwhelmed the students. This guide, in conjunction with the students’ interpersonal interactions, keeps the activity in their “zone of proximal development” [16].

While further, rigorous evaluation is necessary, we agree with one of our reviewers that RabBit EscApe “seems novel and engaging, and likely to be of interest to many other researchers, and to spark interesting debates.”

5. CONCLUSION

A significant leap must be made to educate our youth as society continues to develop computational systems with which they must interact. Along these lines, we have developed RabBit EscApe to teach CT in a relatively explicit way, intentionally moving the focus of the game away from mathematical concepts, which are predominant in other CT game setups. Having run a study to observe children’s interactions with each other and our game, we believe there is a promising avenue for low-tech, tangible games for teaching CT to children aged 6-10 years in an engaging way. Our next step includes running a formal study to assess the game for its appropriateness in cultivating CT skills, and verify if the designed strategies support these skills in a successful manner.

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7. REFERENCES