State Machines are Child's Play
Observing children ages 9 to 11 playing Escape Machine

Michael Philetus Weller
Computational Design Lab
Carnegie Mellon University
Pittsburgh, PA 15213 USA
philetus@cmu.edu

Ellen Yi-Luen Do
ACME Lab
Georgia Tech
Atlanta, GA 30332 USA
ellendo@cc.gatech.edu

Mark D Gross
Computational Design Lab
Carnegie Mellon University
Pittsburgh, PA 15213 USA
mdgross@cmu.edu

ABSTRACT

We developed Escape Machine, a puzzle game in which children control the behavior of characters in a maze by manipulating a tangible state machine built with Posey, our computationally-enhanced hub-and-strut construction kit. We observed children ages nine to eleven playing the game in several sessions. The qualitative results of this observation validate the promise of Posey and Escape Machine to engage children in manipulating algorithmic specifications for behavior.

Categories and Subject Descriptors

K.3.1 **[Computers and Education]**: Computer Uses in Education; H.1.2 **[Models and Principles]**: User/Machine Systems; H.5.2 **[Information Interfaces and Presentation]**: User Interfaces.

Keywords

Tangible UI, construction kits, algorithmic specification, games, evaluation.

1. INTRODUCTION

There is a long history of devices and environments designed to help children acquire fundamental strategies for discovering and manipulating the world around them. Froebel's gifts [1] introduce children to strategies for exploring the constraints of space and structure. Logo [3, 6] introduces children to the power of functions, iteration and recursion. We built Posey [8], our hub-and-strut kit instrumented to detect the form and pose of models, to explore ways computation can enhance children's experiences with manipulatives. We have designed our Escape Machine game [9] to investigate whether computationally-enhanced manipulatives can serve as a platform to introduce children to algorithms, as a sort of tangible pre-Logo warm-up activity. Escape Machine is a puzzle game wherein children manipulate a tangible state machine controller built with Posey to control the movement of a group of agents through a maze (Figure 1). We report here on our initial observations of children playing with Escape Machine.

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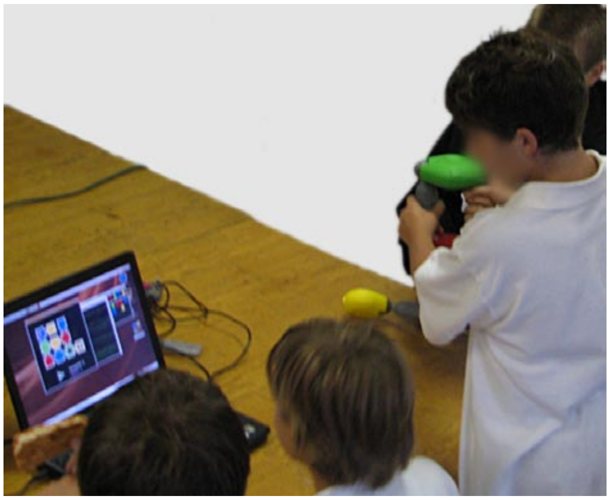


Figure 1. A group of children plays Escape Machine while another group watches.

Several properties of tangible user interfaces (TUIs) make them ideally suited for attracting and introducing novices to a new domain. By building interfaces that embed computational properties in artifacts whose physical attributes are isomorphic to features of a domain, these systems help novices master new modes of thinking [5]; TUIs invite people to pick them up, and engage people in play [4, 7]; and they potentially appeal to a broader swath of society than screen-based applications [2].

Posey's hubs and struts lend themselves to representing the nodes and edges of a graph. Graph representations are useful for a variety of domains so Posey can provide the TUI for exploring a range of concepts, each supported by a different software application that accepts inputs from the kit. We built Escape Machine to engage children with the basics of algorithmic specification and distributed systems, as a stepping stone on the path toward more powerful (but also more daunting) learning environments. To generate interest and provide a well-defined short-term goal that children can reach we decided to create a puzzle game. In Escape Machine you control the movement of several agents through a maze (Figure 3) by building a tangible state machine controller with a Posey kit (Figure 2). In playing the game children implicitly program a distributed system where agents interpret the same small program in different contexts to determine the state of the game on the next turn. For further detail on the mechanics of game play please see [9].

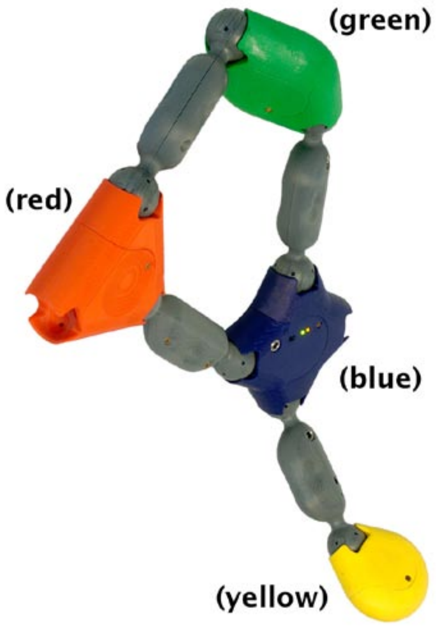


Figure 2. The tangible state machine controller specifies the movement of characters in the maze: A ghost in a red room will go to a green or blue room, preferring the green room because the green hub is higher in the controller.

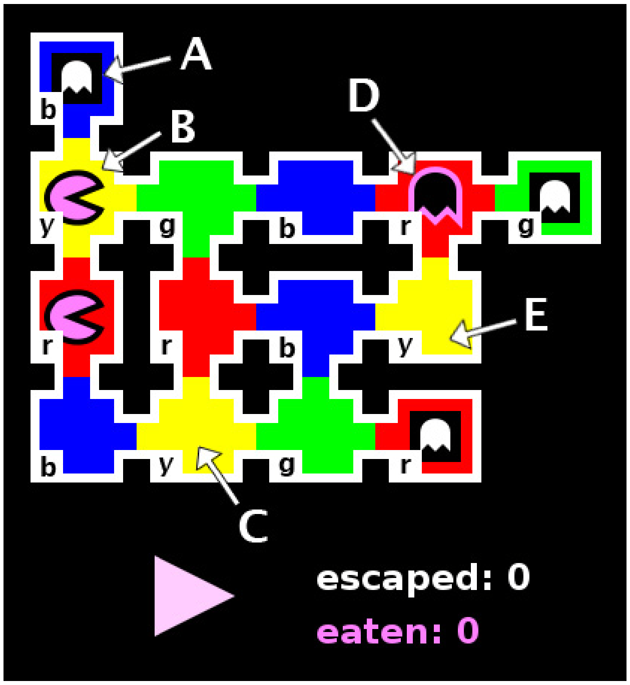
To see whether Escape Machine is, as we intended, an engaging activity for children that scaffolds their understanding of algorithmic specification, we held several sessions observing children ages nine to eleven playing the game. These sessions confirmed that children are both capable of, and excited about, manipulating the tangible state machine controller to navigate the maze. In addition, their comments suggest that they began to extrapolate higher-level concepts governing the behavior of agents after only one or two rounds of play.

In the following section we detail our method for observing children's game play and qualitatively assessing their level of engagement. Next we describe the results of our observation sessions. We conclude with a discussion of the results of this research and future directions for this work.

2. OBSERVATION PROTOCOL

We designed Escape Machine to engage children in specifying behavior algorithmically. By observing elementary school children playing Escape Machine we aimed to answer four questions:

1. *Interest*: Will children of this age be interested in playing Escape Machine?
2. *Capability*: Will they be able to play through an entire maze?
3. *Comprehension*: Will they understand the game play mechanism?
4. *Strategy*: Will they be able to identify higher-level strategies for game play?



escaped: 0
eaten: 0

Figure 3. An Escape Machine maze. The goal is to guide your avatar, the ghost (*D*), to rescue your friends, the imprisoned ghosts (*A*), without allowing the ghost eaters (*B*) to eat you or your friends.

The first two questions address whether Escape Machine is a reasonable activity for children of this age. The second two questions address whether playing Escape Machine helps children to think about behavior in terms of algorithms.

We conduct our observations as follows: Children play Escape Machine in groups of two or three and we record their conversations. We actively encourage them to describe what behaviors they are trying to accomplish. As they play we also answer any questions they ask about what is happening in the game.

We break game play into a series of sessions, with two teams per session. We begin by briefly describing the Escape Machine game and demonstrating the two key game play mechanisms: (1) Characters move between rooms whose colors are directly connected in the controller; and (2) when connectivity allows more than one valid move the vertical ordering of the hubs in the controller (Figure 2) determines which is chosen (the ghost prefers the highest hub while the ghost eater prefers the lowest). After this introduction, a new level 1 maze (1 ghost & 1 ghost eater) is generated for the first team of children. We suggest that one team member operate the mouse and the other(s) operate the controller, and that they discuss what they are attempting to accomplish. A team may play until they complete the maze (all imprisoned ghosts are rescued or eaten) or are eaten by a ghost eater (although time permitting, we allow a second chance).

During game play we prompt the children to discuss the movements they are attempting to induce, and why they think the current controller configuration will or will not generate the desired result. Although we do not proactively point out errors, we do answer direct questions about game play mechanisms. As children play we note comments that indicate their comprehension of the mechanisms of play, that point to formation of higher level strategies, or that indicate strengths or weaknesses in the game play experience.

3. OBSERVATION FINDINGS

We held three sessions: the first with a group of eight children ages nine to eleven; the second with nineteen children ages nine to eleven; and the third with three eleven-year-olds, and two thirteen-year-olds. The first two groups were composed of children in a summer robotics program; the third group was composed of children who responded to an invitation to play with a robotic construction kit sent to parents.

3.1 Interest and Capability

During the first session, three of four teams completed a maze, and the fourth team only gave up after being eaten twice in fifteen minutes. After all teams had played, one team that was particularly enthusiastic ("*This is awesome!*"; "*Got it! Yay! That was really fun!*") asked to play level 2 (two ghost eaters, larger maze), which they also completed.

In the second session four of six teams completed the maze: One gave up in ten minutes after being eaten and another gave up after hardware failures interrupted game play.

In the third session both teams completed the maze, and the first team (composed of the three eleven-year-olds), which later also played and completed level 2, said that the game was "*a lot of fun.*" At the end several children asked where they could buy a Posey kit, and whether they could download the game from the internet.

As might be expected because the groups were all self-selected robotics enthusiasts, we found the level of interest uniformly high, at least initially. Some groups became frustrated by their inability to control the characters' movement. Sometimes the team member managing the mouse would become impatient and hit `go' repeatedly without waiting for the other team member(s) to configure the controller; teams were generally able to recover from this. A few groups had a difficult time understanding the game mechanics and gave up after being eaten repeatedly. However we were encouraged that nine of the twelve teams completed at least one maze. Teams generally took 10-20 minutes to complete a (level 1) maze, and even teams that failed to complete a maze would play for 10-15 minutes before giving up.

3.2 Comprehension of Game Play Mechanism

The most successful teams explicitly discussed game play mechanisms. For example in one exchange the team member working the mouse gives advice on the first mechanism: "*Now we need to get to yellow…blue needs to be connected to yellow,*" and the team member working the controller responds "*Oh, I get it now.*" In another team, the child working the mouse stopped to make sure the controller was configured properly before pressing `go' ("*We want to go to green…is red connected to green?*"). In another team one player noted that "*blue needs to be higher than red or we will go back.*"

A few children failed to understand that two hubs in the controller must be connected directly (rather than through a third hub) for characters to move between rooms of that color. But the most common difficulty was in simultaneously tracking the movement of the ghost and the ghost eaters ("*Connect yellow to red so [the ghost eater] will go to red.*" – "*no but **we** want to go to red*"). Most teams just ignored ghost eaters until they approached their ghost. Some teams then switched strategies and guided the ghost eater away before turning attention back to the black ghost avatar. One team didn't understand that they were controlling the ghost eater movement as well (focusing only on guiding the black ghost avatar to rescue the imprisoned white ghost friends), which resulted in their avatar being eaten. Some children felt that it was unnecessarily confusing to have the ghost prefer the higher hub and the ghost eaters prefer the lower hub ("*I hate the up/down thing!*")

Although children initially found the game play mechanisms difficult ("*This is complicated and confusing!*") many could explain the mechanisms after a few minutes of play and were enthusiastic about their breakthrough ("*it was confusing at first but now I get the hang of it!*"). In the teams that were able to complete the maze, the children's explicit verbal instructions telling team members how to configure the controller to achieve a desired result clearly demonstrated that they understood the basic game mechanism.

3.3 Formulation of Higher-Level Strategies

A few teams moved beyond understanding the basic game play mechanisms to think about higher-level strategies.

One team noted that yellow only has one connection and green only two, while red and blue had more. They decided that "*Yellow's the really hard one*" and "*blue is easiest*" and tried to navigate towards blue rooms when possible, as they could then choose any direction without reconfiguring the controller.

Another team identified the same strategy, and explained that "*blue is attached to all the colors so we can move to all*" the other colors just by rotating and bending the controller. They further generalized this strategy to plan several turns ahead and construct their controller so that they could move to an intermediate goal by just rotating the controller between moves.

One team seemed to stumble upon what we call *the yellow jail strategy*: they trapped the ghost in a red room connected to green and yellow by connecting red only to blue, asking "*Why can't we go?*" The observer explained that with no available connections an agent becomes trapped. That team later trapped the ghost eater in the same red room, and after one of the team members noticed this, they managed to keep the ghost eater trapped until they completed the maze.

In the third session we explicitly demonstrated the yellow jail strategy as a part of our game play demonstration to see if the teams would be interested in and capable of reproducing it. The first team (of eleven-year-olds) explicitly expressed interest in trapping the ghost eater and identified a suitable yellow room. They successfully trapped the ghost eater in a yellow jail, and held it there as they cleared the maze. As they reconfigured the controller, team members reminded each other not to connect the yellow hub to the red hub as that would release the ghost eater. The second team (the two thirteen-year-olds) also identified an appropriate room to trap the ghost eater, but poor team dynamics (one team member's tendency to repeatedly press the *Go* button before the other team member was ready) prevented them from successfully executing the strategy.

The unprompted discussion of strategies by teams in the first two sessions suggests that Escape Machine successfully engaged children in thinking about the algorithmic specification of behavior. The enthusiasm of the teams in the third session for replicating the demonstrated yellow jail strategy suggests that with prompting more of the children would be capable of considering higher level properties of the system.

4. DISCUSSION AND FUTURE WORK

We've described the Escape Machine game, and our experience observing children playing the game. We conclude with a few brief reflections on the work.

4.1 Engaging Children in Computational Thinking?

With respect to our specific goal of engaging children in computational thinking, we cautiously claim initial success: we found that not only are elementary school age children interested and capable of playing Escape Machine, they can describe the game play mechanisms in their own words and sometimes even formulate higher-level strategies for play. Our test population was extremely sympathetic, and we plan to follow up with a group of children that is more representative of the general population. In further evaluations we would look at whether playing Escape Machine provides a platform for more advanced forms of computational thinking. It's computational and it's fun, but does it actually prepare children to work more explicitly with algorithmic descriptions of behavior, or to apply the model of a state machine that is implicit in the Escape Machine in other situations? We plan to investigate these questions as we go forward with this work.

4.2 What Did We Learn About the Game?

With respect to the design of the Escape Machine game, our observation provided specific insights about game play that will inform the next version of the game. Several groups were distracted by the several windows (used for debugging) on the screen, and requested a full screen mode that would let them focus on the maze. Multi-player teams seemed successful, and one child who returned to play a solo round after playing with a partner complained, "*it's hard to do it with one person.*" However in team play the mouse-driving partner sometimes became impatient and pressed *Go* before the other partner configured the controller. Adding multiple controllers for multi-team play could reduce waiting by allowing children to adjust the controller while the other team was moving. We plan to extend Escape Machine to eliminate lulls in game play by adding multiple controllers and streamlining the game rules.

4.3 State Machines for Specification of Behavior

We believe that one of the most interesting results of this work is the initial qualitative validation of tangible finite state machines as a vehicle for introducing computational thinking to children. In Escape Machine this abstraction allows children to manipulate a distributed program that is interpreted in context by each agent in the maze to produce complex global patterns of behavior. And although the mapping between the controller and the behavior of the characters may initially appear hopelessly complex, most children were very quickly able to produce desired behaviors. We believe that this sort of complex distributed system is going to become prevalent as computing saturates our environment, and it is important that we provide children with the conceptual tools to manage the behavior of these systems.

5. ACKNOWLEDGMENTS

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