Moving to Learn: Exploring the Impact of Physical Embodiment in Educational Programming Games

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Abstract
There has been increasing attention paid to the necessity of Computational Thinking (CT) and CS education in recent years. To address this need, a broad spectrum of animation programming environments and games have been created to engage learners. However, most of these tools are designed for the touchpad/mouse and keyboard, and few have been evaluated to assess their efficacy in developing CT/programming skills. This is problematic when trying to understand the validity of such designs for CS education, and whether there are alternative approaches that may prove more effective. My dissertation work helps address this problem. After creating a framework based on a meta-review that carefully dissects embodiment strategies in learning games, I am building and evaluating tangible and augmented reality versions of a CT game. I plan to examine how these different forms of physical interaction help to facilitate and enhance meaning-making during the learning process, and whether/how they improve related learning factors such as self-beliefs and enjoyment.

Author Keywords
Physical Embodiment; Educational Games; Embodied Interaction; Embodied Cognition; Programming; Computational Thinking.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Background and Motivation

In recent years, there has been a substantial amount of public attention around the necessity of Computational Thinking (CT) and CS education with notable calls from the National Science Foundation and president of the United States of America [3, 10]. A broad spectrum of animation programming environments (e.g., Logo [26], Scratch [32], and Blockly [9]) as well as puzzle programming games (e.g., Mazzy [18] and Machineers [22]) have been created to teach these crucial CT skills. However, a recent survey reveals most CT education tools created commercially and academically to be almost exclusively designed for the touchpad/mouse and keyboard [13]. Additionally, few of these systems have been evaluated to assess their efficacy in developing CT/programming skills. This is problematic when trying to understand the validity of such designs for CS education and whether there are alternative approaches that may prove more effective. Furthermore, little is known about whether CT-focused games actually improve other important educational factors for STEM learning (such as engagement, enjoyment, and programming self-beliefs [1, 35]), or if they simply function as chocolate-covered broccoli.

Conversely, recent work has suggested that body-based, physically embodied designs provide affordances that aid in the meaning-making process and offer greater learning benefits than traditional keyboard and mouse games [24, 27, 29]. Two physical approaches of particular relevance within the HCI and Learning Science communities are tangibles/manipulatives [25, 27] and augmented reality (AR) [7, 19]. The primary advantage of tangibles over traditional desktop applications is that they allow for learning concepts to be embedded directly into the physical material and design of an object, as well as through the embodied interactions learners have by manipulating these objects [30]. AR's primary advantage is utilizing embodied cognition to help learners develop understanding through mirroring or enacting learning concepts with their body [19]. These physical design approaches have also shown beneficial effects on key learning factors such as engagement [6], enjoyment [39], and positive feelings towards learning content and science in general [21].

The goal of my research is to explore how the diverse affordances of these various forms of physical embodiment can differ in impact upon the meaning-making process and related factors for learners [23, 24]. This will be done through creation, evaluation, and comparison of educational programming games utilizing different forms of physical embodiment.

Related Work

Physical Embodiment

In my research, I take a broad perspective towards embodiment: centering it around the notion that human reasoning and behavior is connected to, or influenced by our bodies and their physical/social experience and interaction with the world [31]. This is seen as an iterative relationship, where reasoning and behavior can shape interaction as well as the other way round, yet also complex because of the context, time, space, emotion, etc. in which interaction is situated. Applying this perspective in a related work survey I did when constructing a design framework [23], I identified five different forms of physical embodiment: 1) **Direct Embodied** focuses on gestural congruency and how the body can physically represent learning concepts [16]. 2) ***Enacted*** focuses on acting out/enacting knowledge through physical action (i.e., knowledge-as-action) [14]. 3) ***Manipulated*** focuses on utilization of embodied metaphors and interactions with physical objects [2], and the objects' physical embodiment of learning concepts [15, 28]. 4) ***Surrogate*** focuses on learners manipulating a physical agent or "surrogate" representative of themselves to enact learning concepts [8]. 5) ***Augmented*** focuses on combined use of a representational system (e.g., avatar) and augmented feedback system (e.g., Microsoft Kinect and TV screen) to embed the learner within an augmented reality system [8].

Computational Thinking

CT is a complex construct with a wide variety of definitions. However, [4, 5] have identified a core set of CT skills commonly utilized in the literature as: 1) *Conditional Logic* - the use of an "if-then-else" construct; 2) *Algorithm Building* - a data "recipe" or set of instructions; 3) *Simulation* - modeling or testing of algorithms or logic; 4) *Debugging* - the act of determining problems in order to fix rules that are malfunctioning; and 5) *Abstraction* - use of procedures to encapsulate a set of often repeated commands.

Tangibles and Computational Concepts

There has been some work in the tangible and embodied interaction community on the creation of tangibles to teach computing concepts such as roBlocks [34], Note Code [20], Thingy Oriented Programming [12], TanProRobot 2.0 [37], and Electronic Blocks [38]. However, concepts covered by these tools are focused on physical computing, electronics, and music rather than actual computational thinking or games.

Problem Statement

The primary question addressed by my research is: *How do different forms of physical embodiment and interaction impact learning in educational games?* I am working towards answering this question in the context of educational programming games. From this, there are three main sub-questions guiding my work:

1. What affordances do different forms of physical embodiment and interaction provide to facilitate meaning-making during the learning process?
2. What forms of physical embodiment prove more effective for learning certain Computational Thinking skills and why?
3. Do different forms of physical embodiment and interaction have differing outcomes on related learning factors such as self-beliefs, cognitive load, enjoyment, and engagement?

Research Goals and Methods

Based on the above questions, the goal of this research is to explore if applying physically embodied designs results in improved learning outcomes for core CT skills (i.e., Algorithm Building, Abstraction, Simulation, and Debugging) and related learning factors. I have already laid the theoretical groundwork for this examination through the creation of a design framework for embodied learning games and simulations [23, 24]. Using the design framework, my aim is to create different versions of a CT game called Bots & (Main)Frames based on common forms of physical embodiment and evaluate/compare/refine them across three studies with novice programmers.

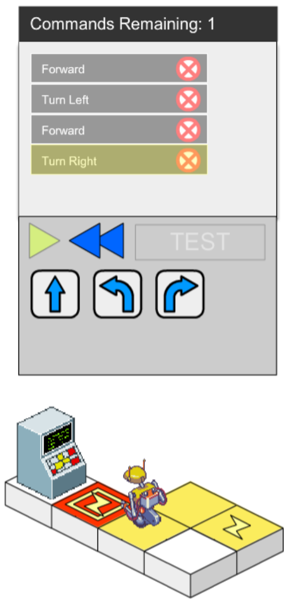

Figure 1: The prototypical keyboard and mouse CT game.

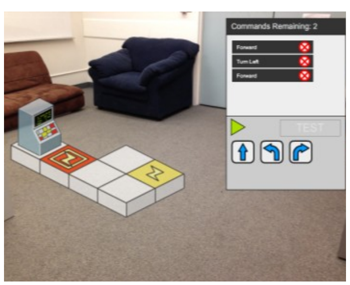

Figure 3: The proposed AR version of the CT game.

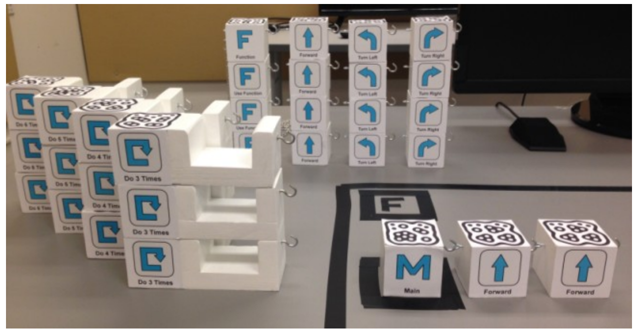

Figure 2: The tangible programming blocks version of the CT game.

The first study will compare the prototypical CT puzzle game version for mouse (see Figure 1) with a tangible programming blocks version utilizing fiducial tracking from the ReacTIVision framework [17] to program (see Figure 2). The second study will compare these against an AR version where programming is touch-based on a tablet and players instead enact execution of their code by walking through physical space (see Figure 3). I plan to analyze learning outcomes for these studies using a between-subjects design with video recording and qualitative coding/analysis [33] to identify occurrences of CT and physical embodiment during play. This will be done in conjunction with assessments of programming self-beliefs [36], cognitive load [11], and enjoyment to compare improvements in key learning factors.

For the third study, I plan to use prior findings to iterate and refine existing designs of the tangible and AR games to enhance their efficacy before reevaluation with a K-12 population. The doctoral consortium will prove especially beneficial to my work for this aspect since I will have both of the original designs to present and feedback will greatly benefit the iteration process.

Expected Contributions

Through this dissertation work, I expect to make the following contributions:

1. Empirical and artifact-based contributions towards understanding the design space of physically embodied educational games, in the form of a design framework [23, 24] and evaluated physical computational thinking games.
2. New understanding and evidence concerning how physical embodiment and interaction can impact meaning-making during the learning process.
3. Design suggestions for creating engaging and enjoyable educational programming games.

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