Augmenting Embodied Mathematics Classrooms with Mobile Tutors

Abstract

We present the Wearable Learning Cloud Platform (WLCP), a web-based platform that supports embodied educational game creation, play, and math learning in real classrooms. It is a novel learning technology that supports students' exploratory movement within learning environments, blending with classroom culture, hands-on activities, and collaborative games. We present evidence from several experiments that show that a variety of embodied games created via the WLCP help students learn mathematics in real K12 school settings and afterschool programs.

Objectives

We present a platform for collaborative, game-based learning called the Wearable Learning Cloud Platform (WLCP) that enables students to move about and explore their environment while guided by mobile devices (cellphones). WLCP enables students to play social and active games that stimulate mathematical thought and embed embodied activities into the realities of classrooms, curricula, and standards [6, 27]. The WLCP supports multiplayer, interactive, gamified experiences that use cellphones in full classes of K-12 students [27, 28, 33]. While using the WLCP, students can manipulate objects available in the physical environment to take measurements, compute, estimate, and gesture while interacting with their peers and teachers in rich discourse. As game players, students use cellphones to solve quests and math problems. As game creators, teachers deepen their math knowledge by designing math games that target the curriculum their students are learning.

Prior work has assessed the feasibility of teachers, researchers, and even students creating physically-active multiplayer math games with the WLCP, identifying any challenges that they might encounter [6, 15]. Math game playing and/or creation with the WLCP has been implemented with roughly 500 elementary, middle, and high school students as well as 20 math teachers so far, who have created a variety of games for students to play, as part of a 7-hour teacher professional development program [41].

This article summarizes the results of studies run in schools. We focus on the game products themselves, created either by teachers or researchers, and their outcomes on mathematics learning when deployed in classrooms or afterschool programs.

Theoretical Framework

Embodied Cognition. In recent years, cognition has taken on a broader perspective and is believed to be distributed among mind, senses, motor capabilities, and social interactions [42]. This theory of *embodied cognition* assumes that sensory perceptions, motor functions, and sociocultural contexts shape the structure and development of thinking skills, including mathematical thinking [20, 37]. Learning is considered to be *embodied,* involving the creation, manipulation, and sharing of meaning through bodily interactions [25]. Students may be guided to encounter, discover, and rehearse perceptuo-motor schemas in relation to mathematical concepts and relationships [5, 31]. Various literature has associated cognition to action, and supported the idea that physical motion aids educational activities (see Macedonia [26] for a review). Some of the research on the externalization of ideas as hand motion gestures suggests that there is motor encoding of our mathematical ideas, and thus, that mathematics teaching should probably use bodily motion and hand gesturing.

Meanwhile, mathematics teachers commonly use tangible manipulatives in their classrooms, (e.g., tiles, number lines, geometric shapes) more so at the elementary school level [13, 22, 30]. The use of manipulatives offers an alternative beyond worksheets to understand and explore math concepts. While teachers need to provide guidance to bridge concrete representations to abstract concepts, studies have found a benefit for using and acting on objects [14, 23, 40].

Despite this focus on collaborative and embodied learning, most learning technologies for mathematics have been limited to one-to-one student-computer interactions. Only recently has research started to explore how pedagogical agents may gesture to explain concepts within learning technologies [10]. Embodied learning technologies that embrace embodied cognition should imply moving the interface "off the screen", to experience phenomena and relationships that are hard to just watch [21, 32]. This shift would allow students to explore new metaphors through observation, communication through gesturing, and manipulating physical objects in the actual world.

The Wearable Learning Cloud Platform. Mobile devices provide great potential to augment educational contexts and promote tangible, mobile, and ubiquitous learning, as technological devices have become more portable, less cumbersome, and even wearable; they are light, easy to wear, and capable of tracking large amounts of physical activity and individual information [9].

The promise of embodied learning technologies is a new form of learning environment *augmented* by technology that naturally blends into the classroom to facilitate interactions between teachers, students, and the curriculum, where collaboration and face-to-face discourse and gesturing between students and teachers is a natural ecological part of the problem-solving and learning process. An important challenge of embodied technologies is maintaining the affordances of embodied interaction while such digital learning environments are deployed with full classes of students, at scale. Few learning technologies that pay high attention to perception have done this in a realistic way, while gathering detailed data from students in real classrooms and providing detailed assessments to teachers e.g. [34].

The Wearable Learning Cloud Platform enables teachers and students to *play*, *create*, and *debug* educational game experiences, as well as *manage* players in games without necessitating any prior programming experience [6, 27]. Anybody can browse public games to play with students as class-wide activities. WLCP users can choose different roles within the platform: *Game Managers* can start an existing game for a group of players. *Game Players* log into a WLCP game from a WiFi-enabled mobile device to access and play games. *Game Creators* visually program and debug games via a drag-and-drop programming interface to specify the behavior of game players' mobile devices that support players throughout the games. Designed for programming novices, even young students have created games. *Game Creators* design their games on paper first and then specify them in the game editor. Once a game is created, any user can log in as *Game Players* to play WLCP games.

Exploring the Impact of Expert-Designed WLCP Games in Math Classrooms

In this section, we describe five WLCP games (showcased in Figs. 1, 2 and 3), created either by researchers (graduate students and faculty) or by a team of math teachers during a 7-hour workshop. We ran an experiment for each game to understand its impact in real math classrooms; students also took a test before playing their assigned WLCP game, and again after playing the game. For each game, we describe:

(a) a brief *overview* of the game,
(b) the *methods* and *data sources*/*participants* for our experiment with the game, and
(c) our experiment *results*, describing change in performance from pre- to post-test (summarized in Fig. 4).

Tangrams Race

Overview. The *Tangrams Race* is a relay-race game designed to teach geometric concepts. Within teams, each player carries a cellphone. Players take turns to run to an end-line, retrieving geometric pieces whose description is specified in the cellphone. Once students find a piece considered correct, they enter a color code that identifies the shape (a sticker on the shape) and receive immediate feedback: if correct, the player runs back with the shape to tag the next teammate. Otherwise, they ask for hints until they succeed. Once all correct pieces have been retrieved, students work as a team to create a final Tangram with their shapes [3].

Methods and Participants. 32 3rd-5th grade students in an afterschool program were randomly assigned either to the *Tangrams Race* or a control condition that received the same problems on a computer.

Results. Students who played the *Tangrams Race* improved by 15% (pretest $M=0.33$, $SD=0.12$; posttest $M=0.49$; $SD=0.24$), $t(17)=5.1$, $p<0.05$. In contrast, students who solved the same problems on a computer did not improve (pretest $M=0.52$; $SD=0.25$; posttest $M=0.48$; $SD=0.26$).

Estimate IT!

Overview. *Estimate IT!* is a measurement and estimation game for elementary school children [38]. It is set up as a scavenger hunt where teams of students search for volumes described in their phones in mathematical terms (e.g. the cellphone could show: *"Find a cube with a 6" side*"). Players are given an unmarked 12-inch stick to support measurement estimations. Players collaborate and discuss geometry concepts present in the game. The game is designed to give hints about how to measure/estimate to find the correct volume (e.g. "Once you find a cube, use the dowel to estimate 6 inches"). Once students find the correct volume, they enter a sequence of colored squares (a sticker on the volume) and receive immediate feedback.

Methods and Participants. 49 children in an afterschool program played *EstimateIT!* Half of these students were assigned to a condition where hints had images of *hand gestures* that students should enact; in another condition, students received textual hints.

Results. Students in the "hand gesture" condition improved (*M=0.64, SD=0.16* on pretest*; M=0.68, SD=0.17* on posttest*, n.s.*), whereas students in the text-only hints barely improved (*M=0.67, SD=0.12* at pretest time*; M=0.68, SD=0.11 at posttest time, n.s.*).

Integer Hopscotch

Overview. *Integer Hopscotch* was designed by two math teachers and a STEM teacher. The game gives students word problems on addition/subtraction of integers, as players walk along a 20-foot number line to find the answer. Students input each answer into a phone to receive immediate feedback and can request a hint about whether they should move forward or backwards. The goal of the game is to work in pairs to complete all of the integer problems by "walking along the number line".

Methods and Participants. 49 6th-graders took a pretest on integer addition/subtraction. Students played *Integer Hopscotch* in groups of 3-4 players, with one cellphone per group.

Results. Students improved significantly from pretest (*M=.62, SD=.26*) to posttest (*M=.79 SD=.17), t(48) = 6.39, p < .001*, after one class period.

Let's Shop

Overview. *Let's Shop* was a game designed by two math teachers and a STEM teacher. The game features real-life shopping scenarios where students need to find the correct price or discount of an item associated with a word problem (e.g. calculating tips, finding the sale price of clothes, calculating tax on a purchase). In groups, students work to figure out the answer and then physically locate the answer on cards scattered in the classroom, like a scavenger hunt. Players enter color codes on the cards into the cellphone.

Methods and Participants. 84 7th-grade students in two math classes took a pretest on percentages, and then played *Let's Shop*, one cellphone per group.

Results. Students improved significantly from the pretest *(M=.57 , SD=.22)* to posttest *(M=.67=, SD=.18)*, t(83)=3.12 , p=.002, after one class period.

What's my line?

Overview. *What's My Line?* is a slope-equation and graph-matching game designed by an 8th-grade math teacher. It involves slope-intercept form of equations to ensure that students can read and interpret equations. In small teams, students are asked to match equations presented on a cellphone with the corresponding line on a paper graph (several lines are drawn) at one of seven different stations around the classroom. Students move through all stations to correctly match each equation to one line on each graph, draw the correct lines on paper pads as they move between stations, before other teams can finish the game. The final drawn game on the team's paper pad reveals a secret shape!

Methods and Participants. 102 8th-grade students played *What's my line* after a pretest on equations.

Results. Students improved significantly from pretest (*M=.48*, *SD=.27*) to posttest (*M=.77*, *SD=.27*), *t(101) = 7.15*, *p < .001*, after one class period.

Significance and Future Work

These engaging embodied games are the beginning of new research at the intersection of problem solving, embodied action and gesture, and learning technologies. The games that teachers and researchers created were implemented in real math classroom settings and showed improvement in mathematics problem solving performance across different areas of math and grade levels, even after short 30-40 minute exposures. All games led to learning gains, and while the results presented don't explicitly reveal it, students were incredibly engaged while playing.

Math embodiment varied within each game. Future research should focus on understanding how physical actions in each game mediates student learning. Teacher-created games were more effective than researcher-created games in general, probably because teachers have more pedagogical knowledge, which allowed them to target specific areas where their students needed improvement, and created tests that effectively assessed the material taught by each game.

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Figures

Fig. 1. Left: Two children playing the "Tangrams Race" game, guided by cellphones logged into the WLCP as *Game Players*. Students wear the cellphone on their wrists to free their hands. Middle: A game being authored through the *Game Editor*. Right: A user logged into the WLCP as a *Game Manager* to start an instance of a game, such as the one children are playing to the left.

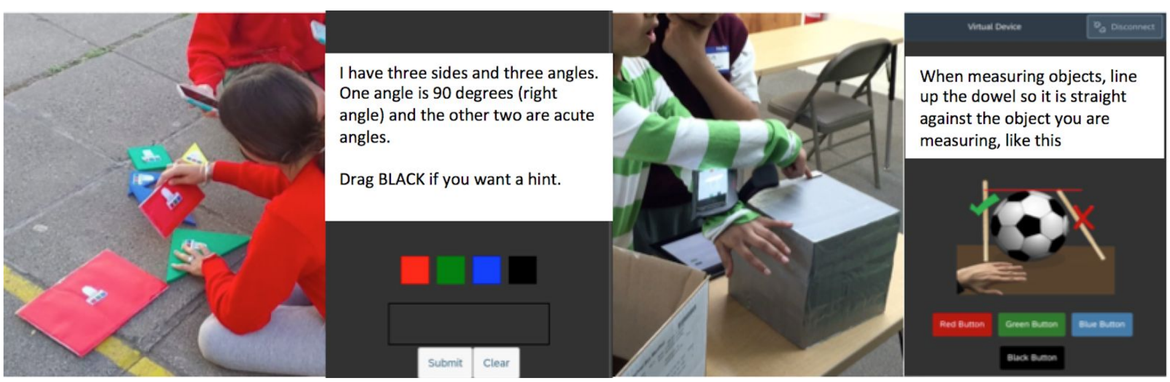

Fig. 2. Left: Students playing the *Tangrams Race* geometry relay-race game, and one screenshot of the cellphone each student carries. Right: Students looking for volumes in the *EstimateIT!* game, considering a cube and a screenshot of the phone each student carries in *EstimateIT!* pointing to motor strategies during measurement, and supporting students in a typical misconception we found.

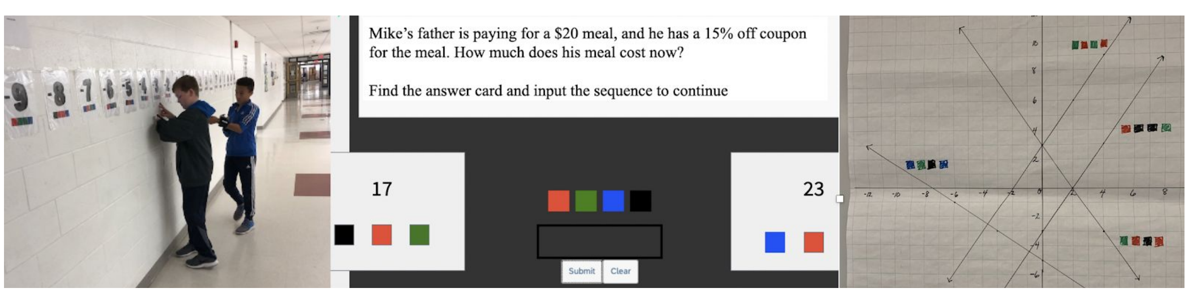

Fig 3. Left: Students walk along a number line attached to the hallway wall as they play *Integer Hopscotch.* Middle: An example display from *Let's Shop* on a player's cellphone, and two paper cards that were potential answers, distributed around the classroom. Right: One of the graph stations featured in *What's My Line?*; teams choose the slope that matches an equation.

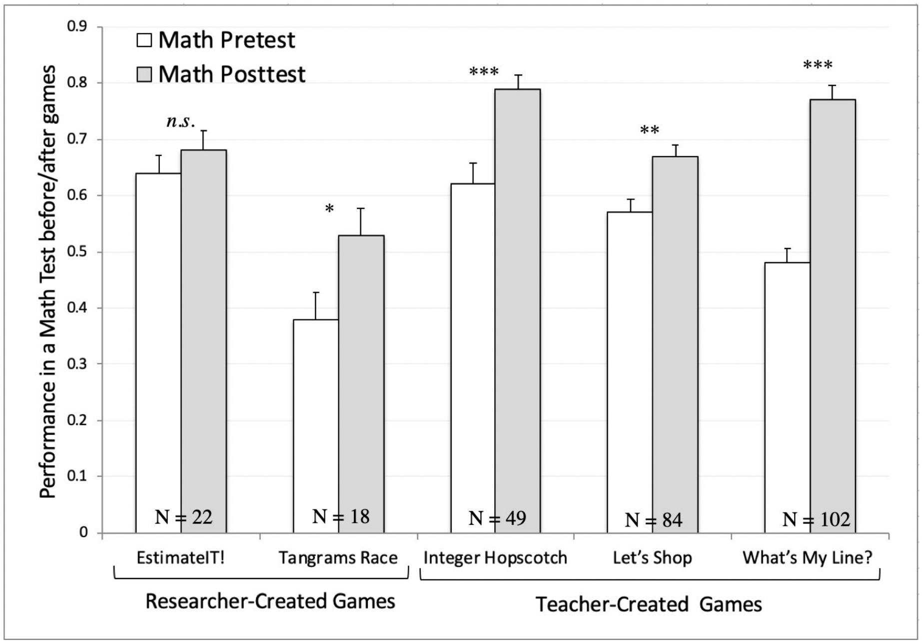

Fig. 4. Improvement in math performance with games created with the WLCP, evaluated in classrooms or afterschool programs. When control conditions in a study were present, the experimental "embodied" condition is displayed, e.g. for *EstimateIT!* the condition with hints that included images of gestures as help/support is shown (* p<0.05; **p<0.1; ***p<0.001 paired samples t-test).