Adopting Montessori Traditions in the Design of Tangible Learning Objects

Zeina Atrash
Northwestern University
Computer Science
Evanston, IL 60208 USA
zeina@u.northwestern.edu

Michael S. Horn
Northwestern University
Learning Sciences
Computer Science
2120 Campus Drive
Evanston, IL 60208
michael-horn@northwestern.edu

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Abstract
This research considers the role of Montessori pedagogy and traditions in the design of new, digitally enhanced educational manipulative materials.

Keywords
Tangible Interaction; Education; Montessori; Algebra

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
This research considers the role of Montessori traditions in the design of new, digitally enhanced educational manipulative materials. In her pioneering work, Maria Montessori considered the sensorial aspect of the physical world to be crucial to child development. She therefore incorporated a variety of physical materials into the classroom environment [5]. The design of these manipulative materials highlights three prominent features that motivate this research: 1) they are used over a long period of time (months and years); 2) they feature subtle uniformities such as color and shape that reinforce the concepts being taught; and 3) they are designed to be adaptable for multiple concepts of increasing complexity [5].

Typically, following a simple lesson that introduces the material, students will continue to use the material in more advanced lessons, building on the experiences gained from previous work. This familiarity is later leveraged to teach more sophisticated concepts hidden within the details of the material's design. Researchers such as Zuckerman have proposed creating tangible manipulatives inspired by Montessori traditions [11]; however, this work emphasizes the representational aspects of the physical objects. Our work builds on this foundation and considers the additional factors of uniformity, adaptability, and continuity to support student learning.

Digitally enhancing materials provides another layer of representation. The duet created by the combination of the physical and the digital can highlight the strengths of both sides supplying the student with modern knowledge of technical tools and access to immense amounts of information, all the while maintaining a feel for the real world and those tendencies that come most naturally to us as humans. The additional tangible element brings support, new exposure, and more room for exploration by providing active assistance and a new dimension for participation by the user [7]. It has been proposed that tangible objects have an important influence on students because they build on existing knowledge and experience that users have acquired from the everyday world which surrounds them [2], and provide students with a greater opportunity for collaboration [9].

This research focuses on developing digitally enhanced tangible materials that create a substantial connection with the child through familiarity and adaptability. Primarily, how can we build on the tradition of Montessori education with the incorporation of digital technology? The goal is to design and develop tangible tools that integrate modern computation, sensors, and actuators to provide students with real-world feedback on their work. In this design process we must incorporate important factors that contribute to successful education, including sensory information, higher-level concepts within simple tasks, and the freedom and responsibility of the child to do work.

The BEAM

As an example of this work, we are developing the BEAM (Balancing Equations by Adapting Manipulatives), a digitally enhanced balance beam, along with a series of lessons designed to reinforce the meaning of algebraic equality. The BEAM, seen in figure 1, consists of one large beam with two arms representing the left and right sides of an equation. Positions are placed across the beam and numbered one through nine in either direction from the fulcrum. Each position represents the coefficient of a term in the equation. Pebbles are pieces that define the type of terms of the equation (figure 2). When the equation that is represented by the pebbles is balanced, the beam will also physically level. Any inequality will result in a tilt towards the heavier side. This tangible device is supported by software to assist in equation creation and manipulation, and validation of results.

Balance plays an important role in studying and defining cognitive development. Various forms of the balance beam have been used to understand children's perception of conservation, representation of knowledge, comprehension of rules, and the communication of conscious and unconscious knowledge [3, 8, 10]. Through such studies researchers have identified various phases of development that children achieve through balance exercises. The metaphor of balance extends to many topics, particularly algebra education. Two popular examples are the Virtual Balance Scale [6] and Hands-On Equations [1]. Alibali and colleagues have intently studied students' misconceptions of the equal sign as an operational rather than relational symbol—a misconception that negatively affects students' performance on algebra assessments [4].

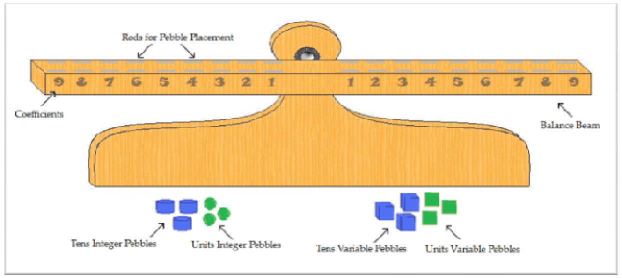

figure 1. The BEAM. The BEAM is constructed from one large wooden beam on a hinge. Rods are lined along the length of the BEAM for pebble placement. Each position is labeled with a number that represents that position's coefficient value. Pebbles come in two types denoted by shape (integers – round; or variables - square), and two amounts denoted by color (units – green; or tens - blue).

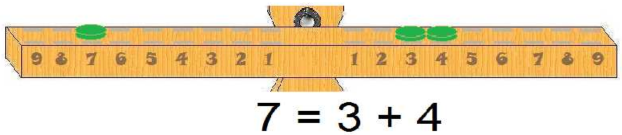

figure 2. Illustration of the solution for the equation 7 = 3 + 4 on The BEAM.

To address this concern, we propose introducing the BEAM at a young age to teach the concept of balance and equality. As the child grows and becomes familiar with the tool, the lessons progress from simple balance exercises through mathematical processes such as addition and the integration of variables in algebra. Ideally, as students reinforce their skill in balancing equations, they will also develop an understanding of other physical concepts such as torque. This material also provides opportunity for extension to other similar subjects, such as balancing chemical equations, with the simple integration of new pieces.

Future Research

We hypothesize that by dynamically linking the physical and symbolic representations, The BEAM reinforces the metaphor of physical balance in the context of algebraic equality. This is applicable for both the physical and virtual representations; however, we hypothesize the physical will have a greater influence reinforcing of the metaphor. In order to test our hypothesis, The BEAM will be incorporated into local elementary level classrooms during sessions on balancing equations. Specifically, we will separate the students into four methods of learning: traditional methods of the classroom, a virtual representation of The BEAM, a tangible representation of The BEAM, and the tangible representation of The BEAM supported by a virtual representation. By analyzing the students' performance on and understanding of algebraic processes and equation balance across groups we can formulate a more thorough understanding of the features important to students during this process.

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