Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design

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Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design[1]

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Contents

Abstract

Robotics toolkits and physical computing devices have been used in educational settings for many decades. Based on a techno-historical analysis of the development of 30 years of development of these devices, this monograph examines their design principles and presents a framework for the analysis and future design, based on the analytic construct of "selective exposure," which examines what is foregrounded or backgrounded in hardware and software design. Selective exposure has two sub-dimensions: usability, which examines how the material communicates rules for its use, and power, which looks at how cognitive and physical operations are mapped to each other, and how the design can make these connections more explicit. I show how these dimensions crucially impact what children can achieve with these materials, and make the case for the design of toolkits in synchrony with the childŠs developmental trajectory.

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Introduction

Archeologists can reconstruct a dinosaur from fragments of a bone, and biologists can infer the Earth's temperature millions of years ago by examining fragments of fossil DNA. Technology historians have also looked at details of simple machines over the millennia as a proxy for the technological level of different civilizations. Semiotics, a "science of detectives," infers larger meaning by looking at details in language, gesture, or prosody Blikstein [1993]. When we do not have access to the entire object, but need to understand the beast, we create indirect ways to complete the puzzle. In this monograph, my goal is to historically and technologically analyze physical computing devices designed for children, derive categories of design decisions, and create theoretical and design frameworks to guide designers and researchers. This is timely, given the growing presence of these devices in formal and informal education.

The presence of several types of physical computing and robotics devices in educational settings is attributable to many research and design initiatives of the past 30 years. However, although the design of such devices has evolved significantly and their popularity has grown wildly, there is little research that examines this technology taking into account their history and the theoretical underpinning that guided their design.

But before delving into these frameworks and devices, it is crucial to understand a few of the educational ideas that guided the pioneers in this field. As we will see throughout this monograph, much of the inspiration and early work came from Seymour Papert's research group at the MIT Media Laboratory. Before coming to MIT, Papert had worked with Jean Piaget, who was the proponent of Constructivism, a very influential theory of human cognition and development. One of the important ideas in Piaget's model is that for a child to abandon a current theory about the world, it takes more than simply being exposed to a better one. The new theory has to emerge from students' complex experiences and actions in the world. Papert added to this theory the idea that this happens more robustly if the learner is engaged in building a public, shareable "object," such as a robot or a computer program [Papert, 1980] — and called his new variation "Constructionism." In other words, Papert was very concerned with not only how to promote sophisticated ways for children to interact with the world (for new knowledge to emerge) but also in making sure that they had at their disposal rich materials and toolkits to build those sharable objects. Therefore, much of Papert's group work was about theorizing about how to create toolkits, programming languages, and other materials for children.

Papert opens his most influential book, Mindstorms [Papert, 1980], with an essay about the "gears of his childhood," in which he talks about how his own experience playing with gears and differentials as a young child generated a deep affective connection with multiplication tables, equations, and mathematics in general: "By the time I had made a mental gear model of the relation between x and y, figuring how many teeth each gear needed, the equation had become a comfortable friend." Papert's computational toolkits ultimately intend to create these same connections in new domains such as engineering, robotics, and cybernetics:

> "A modern-day Montessori might propose, if convinced by my story, to create a gear set for children. But to hope for

> this would be to miss the essence of the story. I fell in love with the gears. This is something that cannot be reduced to purely "cognitive" terms. Something very personal happened. [...] My thesis could be summarized as: What the gears cannot do the computer might. The computer is the Proteus of machines. Its essence is its universality, its power to simulate. Because it can take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes. This book is [my attempt] to turn computers into instruments flexible enough so that many children can each create for themselves something like what the gears were for me." [Papert, 1980]

One contribution of the current work is to identify whether and in what ways, and along what dimensions, designers of physical computing toolkits can use the principles of Constructionism in their own work.

I start the monograph by reviewing the history of microcontrollers and robotics in education, comment on their design principles and forms of interaction, and propose a set of analytic constructs to interpret design decisions. Using these constructs, I more deeply analyze representative examples to understand their affordances and usability, and finally I propose principles for theoretically-guided design. The theory I propose addresses three under-researched issues in the literature and design about the design of robotic toolkits:

(1) What are the levels of abstraction exposed to students and what interactions do they afford?

(2) What are the direct connections between specific design decisions and the learning goals intended for each toolkit?

(3) How should toolkits be considered as part of a larger developmental trajectory?

To address these questions, I first divide the history of these technologies into five generations, spanning 30 years of research and development. I then propose a categorization based on the design commitments and principles of these five generations of devices, employing the analytic construct of "*selective exposure*," which examines what is foregrounded or backgrounded in hardware and software design (this construct will be fully explained in Section 4). Selective exposure has two sub-dimensions. Selective exposure for *usability* examines how the material communicates rules for its use — in other words, how the design embeds error correction schemes (for example, self-correcting polarity errors). Selective exposure for *power* looks at how cognitive and physical operations are mapped to each other, and how the design can make these connections more explicit so that users can exploit the full potential of the toolkits (for example, parts can be designed to explicitly show a hierarchy). Thus, selective exposure for usability guarantees a low-threshold for users to quickly start building, and selective exposure for power assures a high-ceiling by indicating through the design the more complex possibilities offered by the toolkit. Finally, I propose the idea of *selective unveiling*, a design principle which advocates the progressive exposure of layers of abstraction in synchrony with the developmental trajectory of children.

I hope that this discussion might move forward a research agenda that exposes children to the powerful ideas in several disciplines through physical computing, leading to better, more theoretically-informed designs.

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