domino: Mobile Phones as Accessible Microcontrollers

Paulo Blikstein
Stanford University
Stanford, CA 94305, USA
paulob@stanford.edu

Jenny Han
Stanford University
Stanford, CA 94305, USA
jlhan@stanford.edu

Kylie Jue
Stanford University
Stanford, CA 94305, USA
kyliej@stanford.edu

Aashna Shroff
Stanford, CA 94305, USA
Stanford University
aashna@stanford.edu

IDC '18, June 19–22, 2018, Trondheim, Norway
ACM 978-1-4503-5152-2/18/06.
https://doi.org/10.1145/3202185.3213524

Author Keywords
Computational thinking; microcontrollers; physical computing; mobile platform; sensors

CCS Concepts
•Human-centered computing → Smartphones;

Abstract
As the importance of computational devices grows in today's technology-driven society, tools for teaching computational literacy are becoming more necessary. While microcontrollers have been shown to be an effective way to develop computational literacy in young learners, microcontrollers' accessibility is limited due to their cost. We present *domino*, a mobile platform that turns the phone into a microcontroller using its inbuilt sensors and actuators. Learners can create their own cause-and-effect apps with the phone's sensors as inputs and existing applications as outputs. In this paper, we reflect on the design aspects of *domino* that enable learners to use their phones to problem-solve in everyday life, as well as the app's implications for future work in the area of computational literacy.

Introduction
As computers become an ever-present force in not only our daily lives but also the occupations of today's society, computational literacy — the ability to understand, interact with,

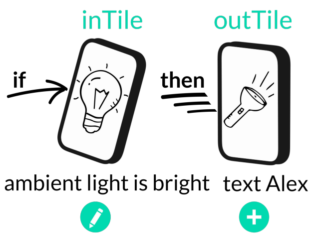

Figure 1: An example of a domino, with an inTile and outTile.

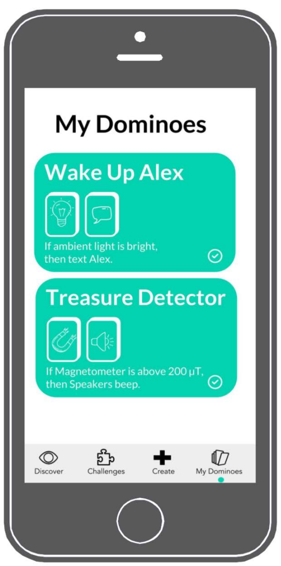

Figure 2: The *My Dominoes* screen with two example dominoes.

and ultimately harness the power of the technologies we encounter — is increasingly important from a young age. Computational tools have expanded from traditional desktop computers to technologies embedded in our daily activities. Yet, this expansion has created a digital divide based on the accessibility of computational devices, as well as the knowledge of how to use these devices. For example, microcontrollers and educational robotics kits have been shown to make computing tangible and to therefore enable students to take on significant projects of varying complexities [1]. But many are still deprived of access to these devices that help teach computational literacy.

In this paper, we propose a mobile platform for physical computing: *domino*, an application that turns the phone into a microcontroller using its inbuilt sensors and actuators. Learners can create their own cause-and-effect apps with the phone's sensors as inputs and existing applications as outputs. Given the increasing prevalence of mobile devices, especially in low-income communities, we believe that *domino* has the potential to expand access to computation as a medium for creativity and expression.

Background and Related Work

Many new learning tools have emerged for promoting computational literacy and thinking in K-12 contexts [2].

Microcontrollers in education

Microcontrollers such as the Arduino and the GoGo Board have proven to be a particularly effective tool for teaching computing [1]. However, their accessibility continues to be a concern. For example, the Arduino, despite its deliberately low-cost design, can still be unaffordable in many low-income communities[1]. In addition, many microcontrollers require the use of computers, rare commodities in low-income households. Research shows that only about 32 percent of low- and middle-income households globally had access to a computer in 2015 [6].

Mobile phones, on the other hand, are far more prevalent. About 60 percent of people from low-income communities and about 98 percent of people from middle-income communities have cellular telephone subscriptions [6]. In particular, more people have begun to have access to smartphones as teenagers [5]. Therefore, there exists significant reason to explore the potential of smartphones as simulated microcontroller devices to expand access to computing tools in low-income communities.

Smartphones for computating

Using the phone as a simulated microcontroller device requires leveraging its many inbuilt sensors, including an accelerometer, a gyroscope, a camera, and more. Apps like Lab4U and Google Science Journal use these sensors to transform the phone into a scientific inquiry tool. However, they do not provide any opportunities for users to program logical relationships between sensors and actuators on the phone. One application that allows users to logically chain the phone's software functionalities via conditional statements is If This Then That (IFTTT). However, IFTTT does not provide access to phones' sensors and therefore does not turn the phone into a physical computing platform.

Design

domino is a mobile platform that aims to create a more accessible microcontroller functionality for children to learn computing. We target learners at the beginning of their smartphone use — often teenagers in middle school or

[1] Low-income communities are those with a GNI per capita of $1,025 or less in 2015; middle-income economies are those with a GNI per capita between $1,026 and $12,475. Together they comprise of a population of 6.15 billion people, about 85 percent of the world's population. [6]

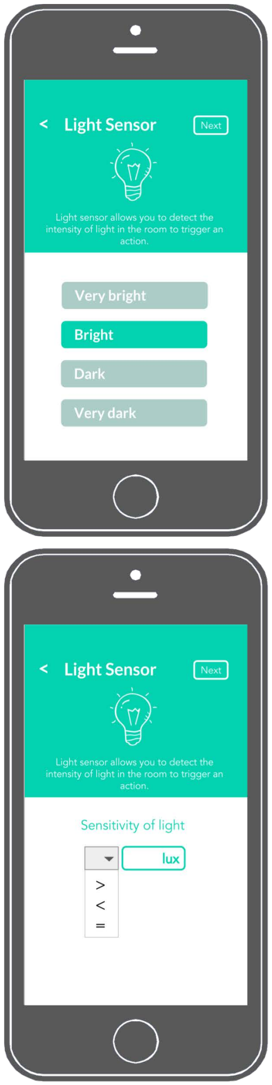

Figure 3: The scaffolded light sensor (top) and the raw light sensor (down).

early high school. Learners can create their own cause-and-effect apps with the phone's sensors as inputs and existing applications as outputs. For example, Figure 1 shows a domino that texts a friend to wake up when the light sensor detects a particular brightness in the room. Other applications could use accelerometer to create an "if shaking detected, then play music" domino or the magnetometer to create an "if metal detected, then beep" domino.

We decided to build the application on an Android operating system in order to reach as many smartphone users as possible, particularly in low-income international communities. Addressing the limitations of current learning tools for computing [Table 1], we designed *domino* with three main principles discussed in the next sections.

Using graphical-based programming
In order to make our application more accessible to beginners, we created a graphical programming interface. Block programming, the most traditional graphical programming interface, was not suitable for a mobile phone due to its small screen size. Instead, we use a visual interface that focuses on the cause-and-effect aspect of computing. Specifically, we use dominoes as a cultural form [3] to represent cause-and-effect applications, or conditionals in programming: domino chains have a clear starting tile — an input — that knocks over a subsequent tile — an output.

Learners create their own "domino" which consists of an "inTile," the cause, and an "outTile," the effect [Figure 1]. Input options include all of the phone's internal sensors, such as the accelerometer and gyroscope, as well as services such as GPS, camera, and the microphone. Output options include triggering phone apps and services such as texting, turning on the flashlight, and playing music. Once a domino is created, the learner can store it under *My Dominoes* and toggle it on or off to activate it [Figure 2].

Feature	*MC*	*Sensor apps*	*IFTTT*	*domino*
No external hardware required		✓	✓	✓
Graphical-based programming	✓		✓	✓
Quickstart for beginners		✓	✓	✓
Domain-generic educational tool	✓			✓

Table 1: Existing approaches (Microcontrollers [MC], Google Science Journal and Lab4U [sensor apps], If This Then That [IFTTT]) vs. domino

Accessing the phone's internal sensors
We chose to glassbox access to the phone's internal sensors so that learners can better understand their phones' capabilities. Our app receives the raw data from phone sensors; however, since learners may find it difficult to translate these raw numbers to physical concepts, we provide simplified versions of some sensors with scaffolded values. For example, rather than indicating brightness using the unit "lux," a learner can use the "simple light" sensor to indicate a provided brightness level (very bright, bright, dark, very dark), and only later gain conceptual understanding of what the unit "lux" means [Figure 3]. More experienced learners can still program with raw sensors to build more complex dominoes.

Enabling exploring and remixing
When getting started, beginners can find project ideas of varying levels of difficulty in the *Challenges* section [Figure 4]. Furthermore, learners can access a growing collection of dominoes in the *Discover* section, where they can view and edit dominoes made by their peers [Figure 5]. Using publicly shared dominoes as templates for creative variance gives learners a sense of ownership [4].

Figure 4: The *Challenges* tab provides scaffolding for milestones and ideas.

Figure 5: The *Discover* tab displays other users' dominoes, which learners can save and remix.

Future Work

In order to allow users to create and share applications of varying complexity, we will: (1) Enable sharing to build a community of learners, (2) Show real-time data to scaffold sensor, and (3) Allow the creation of variables and domino chains. The last point addresses current limitations of the domino metaphor by allowing for more complex programming concepts: multiple conditionals and variables can help represent domino chains. In the long term, we plan on developing domain-specific modules that allow learners to understand the prevalence of computation and easily leverage input-sensors and output-functions in a variety of different contexts, such as the arts, science, or fitness. For example, a fitness module could scaffold motion sensors such as the accelerometer or gyroscope to detect gestures like punching or jumping.

Conclusion

We have presented *domino* as a platform to explore the potential of mobile phones as more accessible microcontroller-like functionality. Our hope is that learners and educators will start using *domino* as a platform to co-develop modules for learning and exploration in a variety of contexts both inside and outside the classroom. In line with the same values of agency and collaboration as citizen science initiatives, we imagine that *domino* could be a crowdsourced "citizen engineering" project. By giving any user with a smartphone the agency to design personalized projects, *domino* can be a powerful way for learners across the digital divide to gain computing skills through creativity and problem-solving.

Acknowledgements

We would like to thank Richard Davis, Chris Proctor, and Veronica Lin and the Stanford Lemann Center for Entrepreneurship and Educational Innovation in Brazil for their support.

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