Constructionist Learning at the Group Level with Programmable Badges

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Abstract

This paper reports on early-stage design research oriented towards engaging *groups* of learners in computationally-rich constructionist activities. The work we present here focuses on computer science (CS) instruction, but the approach is applicable across Science, Technology, Engineering and Mathematics (STEM) disciplines. To enable constructionist learning at the group level, we have created a new computational tool: a programmable and open-hardware electronic badge. In collaboration with Parallax, Inc., a leading educational robotics company, we are developing these badges as a research platform that foregrounds social and interactive dimensions of learning. In this paper, we introduce the CCL-Parallax badge, outline our design motivations, situate the badges within constructionist literature, and describe some of our early activities using them, which fall into three broad categories: embodied participatory simulations, computational systems simulations, and social and distributed maker activities.

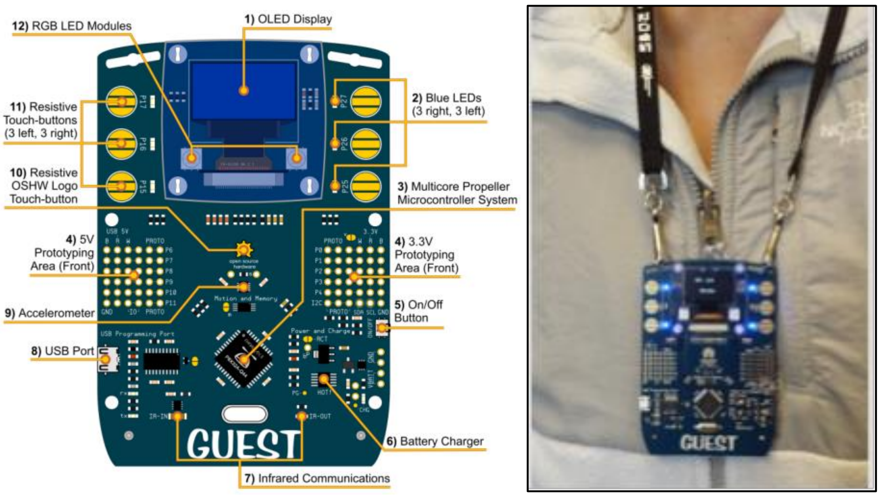

Figure 1. The CCL-Parallax Programmable Badge.

Keywords

Participatory Simulations; Embodied Modelling; Open Hardware; Computer Science Education

Technology for Constructionist Learning at the Group Level

Can a group of learners engage in collective learning activities that are constructionist in nature? If so, what does this look like, and what technologies are needed to support this kind of activity?

We argue that this is indeed possible, and we are pursuing design research to illuminate this space of possibilities. In this paper, we describe several categories of activity that are constructionist both for individuals and for groups as collective learning entities. To support ongoing research in this area, we have developed a computing platform centered on wearable, programmable, and hardware-hackable devices: the CCL-Parallax Programmable Badge (Figure 1). These badges are tuned to support activities that make learning social, shifting images of computation away from work with self-enclosed black-boxes, toward distributed mobile devices and peer-to-peer interactions. Moreover, the badges' wearable nature encourages embodied learning, and their openness at the hardware and software levels enables a range of open-ended construction activities. Our work revives and unifies themes that have appeared throughout the history of research into using mobile computing devices for learning. One important thread emphasized distributed, embodied learning in groups, while another focused on the power of open, simple, and mobile computers to support programming and robotics. Much of this work has built on Papert's constructionist vision of computing and learning (Papert, 1980). Within this broad vision, however, researchers have diverged in the design and educational applications of mobile, personal, programmable devices. With this work, we try and bring those threads back together.

Twenty-five Years of Wearables and PartSims

Early forms of wearable computing had few affordances for learning: they were used primarily in corporate settings to increase efficiency and security, and to provide location tracking of employees (Want & Hopper, 1992; Want et al., 1992). These early badges employed an asymmetric communications model, positioning their wearers as passive objects to be *labeled*. However, a targeted set of improvements enabled a radical expansion of the affordances of wearables. The next wave of research in this area focused on supporting badge wearers in symmetric peer-to-peer and badge-to-badge communications. Making a corresponding shift in metaphor—from badge as *label* to badge as *nametag*—researchers at MIT created Thinking Tags and later, Meme Tags, which were used at conferences to augment conversations between people. These smart nametags were also programmable in a rudimentary way, opening the door to user customization and personalization (Borovoy et al., 1996; Borovoy et al., 1998).

Education research also began exploring how such activities could be used to engage learners in authentic practices of scientific inquiry. In particular, Wilensky and Resnick began exploring how group-centered, embodied activities could illuminate multi-agent computational and social systems. In the late 80's, they created a massively parallel Logo environment, *StarLogo*, which extended single-turtle Logo, to support simulations in which *many* turtles interacted to produce emergent systems behaviors. In concurrent research in *low-tech* settings, they also designed *StarPeople* activities, which allowed groups of *people* to "play turtle" in embodied simulations of complex systems (Resnick & Wilensky, 1993; Resnick & Wilensky, 1998; Wilensky & Resnick, 1995). In such participatory simulations (PartSims) a group of participants *enacts* emergent phenomena through coordinated role-play. Learners individually participate by playing the role of the system's agents that they are representing, and the group as a whole collectively experiences aggregate and emergent behaviors arising out of individual interactions.

Given the complexity and inherent parallelism of both StarLogo models and StarPeople PartSims, a design challenge arose about how to make agent-based insights into complex systems available to a wide audience, using existing technological infrastructure. (Initially, running StarLogo required some of the most advanced computers of the time.) Following one direction, which foregrounded agent-based modeling, Wilensky created NetLogo (Wilensky, 1999). NetLogo enabled both researchers and learners to create and run multi-agent complex systems models using the personal computers that were increasingly available in homes and at schools. Participatory simulations (PartSims) were then added to NetLogo by way of the HubNet module (Wilensky & Stroup, 1999a), enabling a distributed network of computers to run PartSims and making them easy to author in the NetLogo language. HubNet based PartSim research (Wilensky & Stroup, 1999b; 2000) observed significant learning outcomes and new forms and levels of participation, especially with underrepresented groups.

In parallel, a second line of research focused on carrying PartSims work forward utilizing wearable, customizable badges (Colella et al., 1998). This work identified the embodied learning benefits of wearables. For instance, in PartSims simulating the spread of a disease through a population using badges, high school students drew heavily on prior experiences, knowledge, attitudes, and interests (Colella, 2000). In spite of these successes, badge-based embodied PartSims were largely set aside in the 2000s, though some studies with Palm Pilots and other PDAs continued (e.g., Klopfer, Yoon, & Perry, 2005).

Programming and Robotics

While badge-based research focused on using portable and potentially ubiquitous computing devices for embodied PartSims, there was little attempt to involve participants in programming or designing hardware in that work. In contrast, other lines of constructionist research focused specifically on the affordances of small, open computing devices that were similar to badges in architecture and computational power as platforms for learners to build constructions involving both hardware and software. In particular, work in physical computing and robotics advanced the programmability and physical hackability of microcontroller platforms. The Cricket was created in this line of research, intended to allow learners to construct personally meaningful computational artifacts (Martin et al., 2000; Resnick et al., 2000). Such tools involved learners in authentic scientific practices and tapped into prior experiences, interests, and motivations (Martin et al., 2000). This approach remains a successful pathway into computation and scientific practice, as evidenced in the continued popularity of platforms like GoGo Boards, Arduinos, pcDuinos, and Lego Mindstorms. We argue that advances in wearable technology can support an approach that unifies this work with work on embodied social simulation, supporting not only PartSims but also scientific exploration, physical computing, and programming education. In this way, badges can serve as flexible, multifaceted tools for authentic explorations of scientific and computing practices that also foreground the social nature of computing.

Introducing the CCL-Parallax Programmable Badges

The CCL-Parallax badge was co-designed by Parallax, Inc. and the Center for Connected learning and Computer-based Modeling (CCL) at Northwestern University to enable open-ended group activities in an array of settings, from education-oriented conferences to classrooms. The badge comes equipped with an accelerometer, a small OLED display, and IR communication capabilities, meaning it is immediately possible for badges to communicate with each other. It is based on the Parallax Propeller 8-core microcontroller, which is 100% open source (hardware, firmware, and software). Additionally, multiple Integrated Development Environments (IDEs) for the badges include the Simple IDE (SIDE) and the Propeller IDE; and programming language options include the Propeller-C and Spin languages. The badges are also hardware-expandable through an array of solder pads. They are thus designed to be “hackable” at both software and hardware levels, inviting learners to tinker with, and customize, them. Across conference and educational settings, the goal is to engage wearers in computational thinking by offering a rich set of “onboard” functionality with an emphasis on social interactions through badge-to-badge communication.

All of these features support a “high ceiling” for the badges. That is, they ensure that learners will be able to pursue their interests without running into limitations of the technology. However, for the goal of broadening participation in computing, the badges are also intended to have a “low threshold” and be accessible to learners with little or no prior programming experience. For this reason, we are working to develop a blocks-based interface for creating badge programs. This will allow the badges to be programmed with elementary logic that includes access to all onboard functionality including badge-to-badge interactions and communications.

We aim to leverage the inherently social nature of the badges to engage young learners with computing and science practices in activities that position them as creators of personally meaningful constructions. Research has shown how perceptions of Computer Science and STEM fields as asocial and isolated negatively affect young learners’ dispositions to pursue these fields (American Association of University Women, 1994; Barton & Tan, 2010; Brickhouse et al., 2000;

Margolis & Fisher, 2003). Our end goal in providing a "low threshold" entry point is to enable the badges to respond to the interests and expertise of learners as they develop, and to create a novel pathway into STEM and computing learning experiences.

Designing for Constructionist Learning

In constructionist designs, the physical, social, and conceptual dimensions of learning all play important roles in structuring the experience of participants. While the constructionist tradition does not prescribe specific requirements for effective activities, it does lay out a series of guidelines and principles that collectively foster deep and effective learning. We argue that the CCL-Parallax Programmable Badge can support researchers in exploring a new constructionist design space of activities that can engage learners with powerful ideas in innovative ways.

Learning by Making

One of the central tenets of constructionism is that the development of internal knowledge structures can be facilitated through the construction of external artifacts. In *Mindstorms*, Papert uses the Logo programming language as one example of external construction in support of meaning making (Papert, 1980); and similar arguments have been made about construction with physical devices (Eisenberg, 2003). Moreover, improvements in digital fabrication and increased access to these technologies have introduced a host of tangible computing environments that enable new blends between computing and crafting (Blikstein, 2013).

To serve as an effective tool for supporting and investigating constructionist learning in a given domain, a technology must make appropriate tradeoffs between functionality, simplicity, cost, and other factors, as judged by the needs of designs in that domain (cf, Sipitakiat, Blikstein, & Cavallo. 2002; 2004). While the CCL-Parallax badge has been designed to be "protean" in the sense that they invite expansion, their onboard functionality nevertheless determines the type of activities that are their "native ground." This built-in set of features clearly favors social and badge-to-badge interactions. Beyond the focus on IR communications, audio-visual outputs are central hardware components on the badges—from RGB and monochrome LEDs, to the high-density OLED display, to the headphone-compatible audio (and video) output port. Built-in libraries offer simple access to this hardware and facilitate uses that favor embodied social interaction. For example, there is a simple single command to vertically flip the OLED display, enabling switches for text to be read by the wearer (flipped), or by another person (public).

Social Syntonicity

Papert described the kind of learning he hoped to foster with Logo as *syntonic*. For instance, the turtle is *body syntonic* in that children interact with it in ways that are grounded in their own sense of themselves as physical beings navigating the world. It is *ego syntonic* in that their relation with the turtle is coherent with their ideas of themselves and others as beings with intentions, goals, and desires, In developing the badges, we aim to create distributed technology that supports *socially syntonic* learning. That is, we seek to develop a wearable platform for activities that encourage learners to invoke their ways-of-being as social creatures. Our goal is for badge activities to encourage learners to leverage their understandings of how, when, and why they interact with others. We see this as a particularly compelling and novel aspect of the badges, since it brings engagement with computing into the social realm, augmenting existing social practices of learners and broadening the range of contexts in which constructionist learning can occur. If successful, the badges could join other constructionist tools in serving as useful *objects-to-think-with*. Specifically, the badges can support thinking in settings that foreground distributed or group-level behaviors and phenomena. Given the importance of such phenomena to both computer science and STEM disciplines, the badges could be a significant addition to the constructionist design toolkit.

Public and Sharable Artifacts

Early Logo research found that the social and communicative dimensions of the construction process were integral to learning. Harel and Papert (1990) reported that Logo "facilitated the ongoing *personal engagement* and gradual evolution of different kinds of knowledge; and at the same time, it also facilitated the *sharing* of that knowledge with other members of the community, which in turn encouraged the learners to continue and build upon their own and other people's ideas" (p. 33). The integration of public sharing mechanisms has also played an important role in the success of some of today's most widely-used constructionist software (Fields et al., 2014). In making constructed artifacts public, the shared artifacts come to serve as public reflections of the creator's ideas. Furthermore, these artifacts can serve as occasions for conversations - conversations in which the learner is the expert, with valuable knowledge to share. Such discussions can serve as powerful opportunities to disseminate ideas, to gain and give feedback, and to reflect collaboratively with peers. Some of our early activity designs with the badges integrate new opportunities for public sharing, which are enabled by the underlying distributed computing model. In activities that engage learners in creating badge constructions that *communicate*, the iterative programming and debugging cycle also intrinsically involves sharing. Students need to work in pairs or groups even to test their programs; and these social interactions provide opportunities for sharing at all levels.

Powerful Ideas of Computing Made Accessible

Papert argues that an idea is *powerful* if it is seen to be immediately useful to the learner, if it connects to many other productive ideas, and if it is rooted in the learner's intuitive understanding about the world (1980, 2000). Constructionist research in computational thinking attends to the significance of various powerful ideas, be they *practices*—such as debugging and abstraction—or *concepts* and *patterns* that provide explanatory purchase in a variety of domains—such as emergence and feedback. Badges have the potential to expand access to powerful ideas in computing because they can operate not only individually as mobile computers, but also collectively as a distributed computing system.

Activity Structures Supported by the Badges

In this section we briefly describe and categorize some of the activity types that we have explored with the badges. To date, our designs have fallen into three categories.

- Embodied PartSims of social and scientific phenomena
- Simulations of systems significant to computer science
- Social and distributed *maker* activities, emphasizing programming, wearable physical computing, or hardware hacking and expansion

In the first category, we see the badges as a means to carry forward the tradition of embodied PartSims research previously described. As an example, we have done field studies of two versions of a PartSim involving networks and disease transmission with three groups of learners, experimenting with the interactions between the badges, variations in the participant group, and different badge-mediated interaction designs. Two of these studies are described in Brady et al. (2015). Our fieldwork has included teachers in a professional development event; a group of 32 fourth graders in a museum setting; and a smaller group of 11 high school students, also in a museum. The disease activity has two phases. In the first phase, participants interact with each other as well as with badges that are affixed to inanimate objects in the "scenery" of the simulation environment. In the second phase, interaction data stored on the badges is relayed to a central computer, which provides a dynamic, manipulable visualization of these interactions. The group investigates the visualization, to gain an analytic perspective on the shared embodied simulation experience. In this category of work, the badges act as supports for the roles that participants take on in the simulation. Thus, these activities extend the metaphor of "badge as nametag" discussed previously, to a more general role that we call "badge as *costume*."

In a second category of activities, we have designed PartSims that address specific topics and phenomena in computer science. These activities differ from activities of the first category because the badges are foregrounded as computational devices, which are simulating the behavior of components in (other) computational systems. An example is the Wearing the Web activity (Brady et al., in review) in which learners play the role of network endpoints, data packets and routers in simulating a working instant message application. While activities in this category are also PartSims, the computational nature of participants' roles focuses their attention on the mechanisms by which the badges achieve their functions. These activities thus act as a bridge between research in the PartSim tradition and research that is oriented toward supporting learners in programming and physical computing.

In the third category of activities, the badges' computational nature takes center stage. Their behaviors become the explicit focus of collective attention, and the group collaboration is centered on constructing these behaviors. We provide an early instance of a software-focused multimedia activity in this category in the next section: Talking Badges.

Talking Badges

This is an introductory activity that can be used early in students' work with the badges and perhaps as their first experience with programming them. It foregrounds the audio-output functionality of the badges, along with a text-to-speech library that converts specially-formatted phoneme strings into intonated speech. For instance, the following string produces the first seven letters of the familiar alphabet song: "#1aybee+7seedee++ee ef-jee".

The Talking Badges activity provides an open social computing environment in which learners collectively develop computational artifacts of two kinds. First, at the level of *content* they construct and iteratively improve phoneme strings that yield recognizable utterances when run through the text-to-speech engine. Second, at the level of *code* the learners create programs that allow them to render and share the phoneme strings they are building. The "code" goal is pursued as a means of achieving the "content" goal, and both proceed in a distributed, social manner, leveraging the emerging collective knowledge and thinking of the group.

At the start of the activity, students are introduced to the blocks-based programming environment *and* to the phonemic conventions of the text-to-speech engine. They do this by examining a rudimentary initial program that enables them to (a) play pre-defined phoneme strings, (b) send these strings to another badge, and (c) store strings received from other badges into long-term memory, which can be uploaded to a computer when the badge is connected. After a simple demonstration of how to load and run programs onto the badges, how the initial program works, and how to upload strings collected in long-term memory, learners are invited to tinker with the program, changing it in any way they like and using their constructions to make their badges communicate. They are also encouraged to make use of an online class "Gallery" which allows them to post and download digital artifacts (e.g., programs or text strings), enabling sharing, remixing, and so forth.

It is important to note in this activity, while the user is programming, they are not writing programs from scratch. Instead they are modifying and extending existing programs, thus making the activities accessible to those without prior programming experience. And although the blocks-based environment is still being developed, early tests of the Talking Badges with graduate students suggest that text-to-speech is engaging to a variety of learners with a range of prior programming experience. Moreover, "coding" a phoneme string seems to provide a motivating entry point for tinkering with computer code.

Hybrid Activities that Blend these Categories

Because the badge platform is still in its infancy, our initial studies have involved PartSims in the first two categories of activity described above: these activities do not require a fully-developed low-threshold programming environment. However, we feel that a great deal of the innovation potential for the platform resides in the third activity category and also in an entirely new family of activities that *blend* PartSims and Making. For example, consider a PartSim in which participants can contribute to the simulation by modifying the code or hardware of their badges. Extending our existing work on disease spread, we have imagined a family of such activities in which a "viruses" or other pseudo-biological entities are represented a character strings that can be transmitted from badge to badge. Error-prone IR communications can simulate mutations in transmission. Students can be given challenges to create viruses with given properties, to generate "drugs" or simulate immune responses that attack "genetic" sequences, and so forth.

Conclusion

The CCL-Parallax Programmable Badge is designed to make powerful ideas accessible to learners through a variety of group-centered activity types that unfold in a social space and integrate virtual and physical constructions. We believe that badge-based activity designs can bridge between the PartSims and Programming themes within the constructionist research literature, as well as supporting broader scientific exploration and physical computing. This not only allows for activity sequences that incorporate both traditions, but it also opens up a new design space of hybrid activities—including PartSims involving distributed programming and networking scenarios. As we develop a robust learning platform around the badges and iterate the hardware design, we hope to share insights into new social dimensions of learning in computer science and the STEM disciplines.

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