“*That’s Your Heart!*”: Live Physiological Sensing and Visualization Tools for Life-Relevant and Collaborative STEM Learning

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Abstract: Wearable technology and large-screen display systems show potential for helping learners engage in STEM in ways relevant to their daily lives, but it is important to understand how learning activities coupled with these tools can promote rich learning experiences. To advance these goals, our work utilizes a new genre of embodied technology tools for STEM learning—live physiological sensing and visualization (LPSV) tools, called BodyVis and SharedPhys—that display learners’ physiological functions in real-time on a wearable, e-textile shirt and a large-screen display, respectively. We iteratively developed a set of learning activities to evaluate how these tools can support STEM engagement. Our findings show potential for LPSV tools to enable new forms of life-relevant and collaborative scientific learning experiences.

Keywords: embodied learning, STEM, physiological sensing, LPSV tools

Introduction

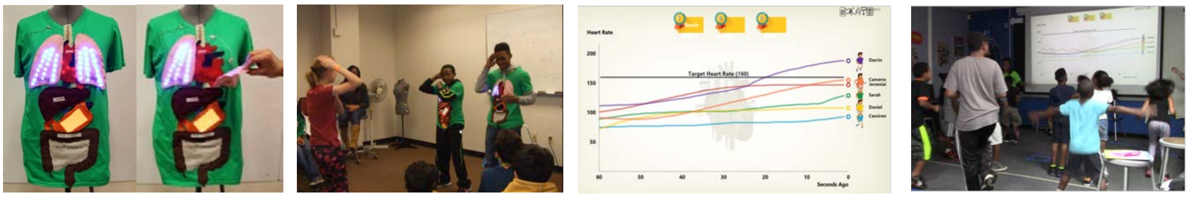
Recent advances in wearable technologies (*e.g.,* fitness trackers) enable new opportunities to make STEM learning less abstract and more relevant to learners’ lives. However, to fully realize the potential of wearables for STEM learning, we must understand how learning activities coupled with these tools can promote meaningful learning experiences. We advance this understanding in the context of live (*i.e.*, real-time) physiological sensing and visualization (LPSV) tools that support embodied learning to promote life-relevant, collaborative STEM learning. LPSV tools integrate real-time physiological sensing and visual displays to promote learning about organ function, physical activity, and scientific inquiry.

Our prior work has focused on the design of two LPSV tools, BodyVis and SharedPhys (Figure 1a and c, respectively), to support body learning and engagement in scientific inquiry by visualizing wearers’ live body-data (*i.e.,* heart and breathing rate) on an electronic textile (e-textile) shirt (BodyVis) and a large-screen display (SharedPhys). We have two high-level goals with our LPSV tools: (i) to help children understand and learn about the body and its connection to the physical world (*e.g.,* eating, exercise), and (ii) to use the body as a life-relevant platform to help children build general scientific inquiry skills (*e.g., Why does my heart rate increase before a test or during soccer practice?).* In this paper, we analyze data from several deployments with a common analytical lens aimed specifically at better understanding how LPSV tools can support life-relevant and collaborative STEM learning experiences for elementary-aged youth.

Our findings show that LPSV tools were relevant to our participants’ daily lives as they connected their own organ functions (*e.g.,* heart and breathing rate) to their everyday physical activities, emotions, and social experiences. Additionally, learners engaged in collective observation, experimentation, and hypothesis generation as they interacted with our LPSV tools. Our contributions include (i) characterizing learning experiences children have with LPSV tools, and (ii) design implications for LPSV learning activities.

Life-relevant and collaborative learning technologies

Our goal is to leverage wearables to deepen learners’ STEM engagement through supporting life-relevant, collaborative inquiry experiences. In life-relevant learning experiences, learners derive meaning relevant to their lives from acting and thinking like scientists (Clegg, Gardner, & Kolodner, 2010). Such experiences enable learners to connect science inquiry and learning to their own interests, passions, and lived experiences (Clegg et al., 2010). Two recent approaches to wearable learning tools illustrate the potential of wearables to support life-relevant experiences by investigating one’s own physical and physiological data: (i) using fitness trackers for math analysis—*e.g.,* comparing sports, validating accuracy of fitness trackers, strategizing workouts based on statistical data analysis (Lee, 2015, Chapter 9) and (ii) exergaming for STEM learning and health knowledge (*e.g.,* Carter Ching & Schaefer, 2015). These approaches offer opportunities for learners to create and engage in new inquiries with data from activities in their everyday lives (*e.g.,* games, sports).



(a) BodyVis **(b)** BodyVis in action **(c)** SharedPhys' Moving Graphs **(d)** SharedPhys in action

Figure 1. BodyVis (a) displays live physiological data on a wearable, e-textile shirt while SharedPhys' Moving Graphs (c) uses a time-series graph representation projected on a large-screen display. Some examples of high-impact activities include dancing with BodyVis (b) and doing jumping jacks with SharedPhys (d).

Our LPSV tools are designed to engage multiple learners in collaborative inquiry either in small groups (BodyVis) or in collective inquiry in whole classrooms (SharedPhys). Collaborative inquiry involves dialog among learners around scientific inquiry practices such as asking questions, designing experiments, collecting data, and developing claims (Chinn & Malhotra, 2001). Collective inquiry occurs when learners are engaged in scientific inquiry as a whole class, collaboratively negotiating problems and working toward a common goal (Lui, Kuhn, Acosta, Quintana, & Slotta, 2014; Lui, Slotta, & Cober, 2012). Embodied learning technologies can be effective for engaging learners in collective scientific inquiry. For example, embedded phenomena systems like *EvoRoom* and *HelioRoom* (Lui et al., 2014, 2012) allow learners to engage in small and whole group activities around asking questions, collecting data, and developing claims backed by evidence from the systems. To our knowledge, our approach to LPSV large-screen displays (Kang et al., 2016) is the first to support collective inquiry and STEM learning more broadly around body-data.

Design

We designed BodyVis and SharedPhys, along with associated learning activities, through an iterative process of participatory design with children and teachers. In this process, we first developed a wearable e-textile approach called BodyVis (Figure 1a), in which physiological phenomena (*e.g.,* heart rate and breathing rate) are visualized on wearable fabric anatomy allowing learners to gain a unique view of the internal body (Norooz, Mauriello, Jorgensen, McNally, & Froehlich, 2015). Next, to support whole-classroom STEM learning and scientific inquiry we developed SharedPhys (Kang et al., 2016). SharedPhys enables collection and analysis of data in real-time across multiple learners by visualizing real-time physiological data from up to six simultaneous users on a single, large-screen display. We focus on one of three SharedPhys designs called Moving Graphs, which transforms wearers' live body-data into line-graph form (Figure 1c). We designed LPSV learning activities through participatory design with (i) an intergenerational co-design team of children (7-11 years old) and adult researchers, as well as (ii) a cohort of 20 teachers in a STEM M.Ed. program. Children suggested competitions and games, while teachers suggested experimenting with our tools by brainstorming high- and low- impact physical activities that would affect the heart rate. Informed by these findings, we iteratively designed SharedPhys and LPSV learning activities to support science inquiry experiences. Our activities focused on having participants use LPSV tools to hypothesize and test physical activities that would lower and raise their heart and breathing rates. We discuss our session protocol in the next section.

Method

We conducted six BodyVis and six SharedPhys study sessions independently. Three of the six BodyVis sessions were reported in (Norooz et al., 2015); here we analyze only the three latest BodyVis sessions which were conducted with our new LPSV learning activities. BodyVis and SharedPhys sessions followed the same format. Each session was approximately two-hours long. Sessions were primarily conducted in out-of-school programs although one BodyVis session was conducted in a joint 2nd and 3rd grade private school classroom. In total, 61 children participated in BodyVis sessions (34 boys, 27 girls) aged 6-13, and 69 children (42 boys, 27 girls) aged 5-13 participated in SharedPhys sessions. Before sessions began, we randomly assigned participants to groups of 4-5 children. We then presented an overview of each respective tool and introduced the inquiry activity. Groups were given a brainstorming period to develop a set of high- and low-impact activities that would increase and decrease their heart and/or breathing rates, respectively. Groups recorded these activities on large notepads, then came back together to present their activities and hypotheses. As each group presented, two BodyVis volunteers, or six SharedPhys volunteers, tested the highest- and lowest- impact activities suggested with the respective LPSV tool. Following each hypothesis test, a facilitator guided a conversation about why they believed the body reacted the way it did.

All BodyVis and SharedPhys deployments were video recorded and researchers also took field notes. For the video analysis of each tool, we followed Chi's eight-step process (1997) using a mixed deductive and inductive approach. Based on observations of a single video, a single researcher developed an initial codebook for observing learners' collaboration (*e.g.,* ways wearers and non-wearers interacted) and life-relevant experiences (*e.g.,* indicators of linking experiences to everyday life, demonstrations of excitement and curiosity) for each tool. Two researchers then met and simultaneously coded a second video for each tool, concurrently updating the codebook. Finally, two researchers coded all videos independently, developed summaries, and then met to discuss and co-interpret the data. One researcher wrote a final summary.

Findings

We report findings related to life-relevance and collaboration for both BodyVis and SharedPhys sessions.

Life-Relevance. With both LPSV tools, participants referenced activities in their everyday lives (*e.g.* playing video games, eating, doing homework) to form their hypotheses of activities that would increase or decrease their heart rates. Each tool also fostered different forms of life-relevance. With BodyVis, participants explored how their emotions affected their physiology. For example, when lying down participants found that, contrary to their expectations, the wearer's heart rate actually increased due to the excitement of the activity. One after-school program regularly required children to reflect on their session experiences at home via a custom-built science inquiry app. Using the app, some participants made similar connections between their heart rate and emotions as they observed their heart rate during other activities: "*Watching the NBA summer league second game brought my heart rate down after running because less blood must be pumped when I am just sitting down and not stressing my muscles and lungs by breathing hard and also the fact that the game was just summer league and not NBA didn't stress me for my team to win.*" SharedPhys created a sense of life-relevance for participants in two ways. First, wearers felt a strong connection with the visualizations because of the live body-data and direct control of visualizations. This was apparent during the hypotheses testing, when both wearers and non-wearers instantly started moving fast (*e.g.,* jogging in place, doing jumping jacks) as soon as the graph was displayed. Second, learners demonstrated excitement and initiated engagement during the hypothesis testing competition where non-wearers cheered their wearer teammates by suggesting movements based on their observations and even mimicking those movements alongside the wearers.

Collaboration. With both BodyVis and SharedPhys, participants collaborated through brainstorming, discussing, experimenting, testing, and revising hypotheses. For activities with unknown outcomes, participants either discussed reasoning behind possible outcomes or placed the activity in an "unknown" category. For example, one group discussed how eating and digestion might affect their heart rate after a group member expressed feeling fatigued following a meal, while another thought their heart rate increased. LPSV tools also fostered unique collaborative experiences. With BodyVis, wearers and non-wearers engaged collaboratively in whole group discussions when wearers tested the groups' hypotheses and reacted to unexpected results. With each unexpected result, discussions—sometimes even debates—organically occurred among participants regarding the body's reaction. For example, one group hypothesized that an activity would decrease the heart rate, but in reality it increased. One group member reasoned that the activity involved more muscle activity than they originally thought: "[You are] *using so much muscles. Your head is going that way, your arms are going this way. So you're using too much energy*." With SharedPhys, most verbal collaboration occurred among non-wearers rather than wearers (as wearers were quite focused on their tasks); however, wearers collaborated non-verbally through observation and physical mimicry. Tasked with making observations about wearers' data as it was visualized, non-wearers often collaborated by helping each other take notes or repeating things that were not originally heard. Wearers would observe and replicate the physical activity of the winning wearer during the hypothesis test competitions. As wearers focused more on their bodies, non-wearers noticed more of the affects of the wearers' physical activities on the Moving Graphs and provided guidance to reach the target heart rate (*e.g., "You're getting lower!" "Get some high knees in there!"*).

Discussion

Our goal was to understand the learning experiences children have with LPSV tools, particularly with respect to life-relevance and collaboration. Here, we discuss the interactions observed in our findings. BodyVis and SharedPhys show that LPSV tools can help learners connect their own everyday activities not only to step and mileage calculations (Carter Ching & Schaefer, 2015), but also to their own organ functions and systems (*e.g.,* heart/breathing rate, muscular system), and to social and emotional factors (*e.g.,* being nervous). Because learners could see body-data change in real-time, they may have been better able to connect the changes of other in-the-moment factors (*e.g.,* body movement, social and emotional context) to the changes they observed in their physiology. This suggests that LPSV tools offer learners opportunities that promote their consideration of the multitude of physical and environmental factors that impact their bodies. Next, while prior work emphasizes collective inquiry around data analysis and development of claims backed by evidence (Lee, 2015; Lui et al., 2014), our analysis suggests that LPSV tools enable other aspects of collective inquiry—collective noticing, experimentation, and hypothesis generation. As participants observed the real-time changes in their heart and breathing rates, they began to collectively discuss other factors simultaneously affecting their bodies. Through these observations, learners generated new hypotheses to test and created new collective experiments (*e.g.,* observing effects of eating). Not only did they collectively discuss inquiry topics, learners often collectively acted. As they observed other groups testing activities, the most effective actions proliferated through the whole group—this sort of collective phenomena is enabled by the visibility of whole-body interactions and the shared, co-located context of the computer-mediated activities.

Wearable tools such as BodyVis require others to be in close vicinity of the wearer, which for some is an uncomfortable experience. LPSV tools and activities must therefore seriously consider learners' comfort and offer multiple types of wearer experiences (*e.g.,* ways to reduce spotlight on learners). Additionally, our analysis suggests LPSV tools have the potential to promote a deeper understanding of physiological concepts, beyond the cause-and-effect of physical activities on the body to social and emotional concepts.

Conclusion

Our work demonstrates the potential of LPSV tools—via the examples of BodyVis and SharedPhys—to enable new forms of life-relevant and collaborative STEM learning experiences. While we found that LPSV tools can support learners' collective observations and experimentations, more work is needed to understand the most appropriate learning contexts for their use and ways that they can complement more traditional, retrospective analysis of body-data (Lee, 2015). Our analysis points to several implications for learning activities with LPSV tools. First, learners need formal and informal time with the tools to play, explore, and delve deeper into inquiry and science content learning. Additionally, learners need opportunities to both *wear* and *observe* LPSV tools as different forms of engagement are promoted through wearer/non-wearer roles. Finally, learning contexts should be flexible to allow learners to try new activities and investigations.

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