Scaffolding Authentic Wearable-Based Scientific Inquiry for Early Elementary Learners

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Abstract: Wearable sensors show promise in engaging youth in scientific inquiry by leveraging physical activity for life-relevant inquiry. Prior research, however, has found that elementary school-age children struggle with the learner-determined aspects of an authentic scientific experiment (*e.g.*, asking a testable research question). We explore how to integrate *wearable-based inquiry* into early-elementary classrooms with *Live Physiological Sensing and Visualization* tools, including: designing age-appropriate scaffolds, adapting to teacher perspectives, and meeting *Next Generation Science Standards* (NGSS). We conducted a two-year, iterative process to develop scaffolds and implement them in four elementary classrooms (two teachers; 90 children). We present two case studies to demonstrate how our participatory designed scaffolds impact the authenticity of the learners' wearable-based inquiry experience. Our findings contribute insights about facilitating wearable-based inquiry with elementary learners and specific supports for using sensor-based learning systems to meet NGSS.

Introduction

With wearable sensors, such as heart rate monitors and accompanying visualizations, upper elementary- and middle-school learners can design and conduct life-relevant experiments using their bodies (Clegg, *et al.*, 2017; Lee & Drake, 2013; Lee, Drake, & Williamson, 2015; Schaefer, Carter Ching, Breen, & German, 2016). We refer to this emerging area as *wearable-based inquiry* (WBI). Unlike traditional classroom science experiments, in WBI, learners explore scientific concepts (*e.g.*, exercise, stress) that are life-relevant. In this way, wearables enable learners to *scientize* their everyday lives (Clegg & Kolodner, 2014)—*e.g.*, their physical activities, body movements, and physiological responses. Grounded in embodied learning theory, which emphasizes the role of the body in facilitating learning (Lee, 2015), our work aligns with the *Next Generation Science Standards* (NGSS; 2013) and the National Research Council's (NRC; 2012) efforts to make classroom science more inquiry driven.

While existing literature has addressed the use of WBI at the fifth-grade level and higher (*e.g.*, Lee & Thomas, 2011), we could find no prior work on how early-elementary learners (first- through fourth-graders) engage with wearables for scientific-inquiry nor the socio-technical scaffolds necessary to support their learning. Prior work in other contexts (Beyer & Davis, 2008) has shown that early learners require consistent and clear scaffolding and struggle to articulate scientific explanations and predictions, and develop procedures. Our aim is to design and evaluate scaffolds that help early learners acquire the skills necessary for conducting WBI. This aim is partially motivated by NGSS (2013), which states that learners should be able to plan and conduct science investigations before the fifth-grade. Our research addresses the following questions: (1) *How do scaffolds impact the authenticity of children's scientific WBI across grade levels?* (2) *How can we design multi-dimensional scaffolds for WBI that integrates technology tools, peers, facilitators, and paper-based materials?*

To address these questions, we present an evaluation of scaffolds used to support early learners in conducting authentic scientific WBI projects with two wearable sensing tools: *BodyVis* and *SharedPhys* (Figure 1). These tools leverage body data for real-time inquiry through *Live Physiological Sensing and Visualization* (LPSV; Norooz, *et al.*, 2016). Children wear a physiological sensor and draw evidence-based conclusions about their bodies by analyzing visualizations of their live heart-rate data as displayed on an electronic textile shirt (BodyVis, Figure 1a) and a large-screen display (SharedPhys, Figure 1c; Kang, *et al.*, 2016). Our research team conducted two one-week deployments of these WBI tools (four in-class sessions across three classrooms): one in 2016 and another in 2017. Here, learners progressed from semi-structured activities (*e.g.*, brainstorming and testing physical activities to see the impact on heart rate) and examples to planning and conducting their own inquiry projects. On Days 3 and 4, learners asked their own questions such as, "*How does my heart rate change when I do the Carlton dance?*" or "*How does my heart rate change when I do my homework?*"

Figure 1. Our two WBI tools: (a, b) *BodyVis* displays live heart and breathing rates on a wearable, e-textile shirt while (c, d) SharedPhys uses a time-series graph representation projected on a large-screen display. Images (b) and (d) show children testing activities with BodyVis (resting) and SharedPhys (push-ups), respectively.

Through a design-based research approach (Sandoval & Bell, 2004), we iteratively designed scaffolds using participatory design with teachers, classroom deployments, and teacher and child feedback. Using a multiple case-study methodology (Yin, 2014), we identify similarities and differences among the authenticity of WBI projects and the influences of our iterated scaffolding from 2016 to 2017. Our findings illustrate how researchers can construct age-appropriate scaffolds for early learners conducting WBI.

Related work

Prior work has shown that early learners can conduct their own meaningful life-relevant science inquiry (Clegg & Kolodner, 2014). Our design is therefore based on Chinn and Malhotra's (2002) framework for scientific inquiry, which highlights learners' freedom to select questions of interest. On a national level, elementary-age learners are encouraged to design and conduct inquiry projects that reveal patterns in their environment and make evidence-based claims (NRC, 2012; NGSS, 2013). Using a constructivist approach, we believe scientific inquiry is powerful for young children because it leverages their pre-existing knowledge and enables them to ask questions about their daily lives and bodies that then drive the inquiry process as opposed to directing their inquiries to predetermined investigations (Chinn & Malhotra, 2002; González, Moll, & Amanti, 2005; Hmelo-Silver, Duncan, & Chinn, 2007). Our embodied approach (Lee, 2015) specifically links these aspects of children's scientific inquiry, as well as their physiological and mathematic learning to their everyday body movement.

Prior work emphasizes that early learners can reach tasks that they could not independently achieve with scaffolding because the work is guided by, for example, paper-based materials (*e.g.*, worksheets) and other knowledgeable people (*e.g.*, facilitator- and peer-based scaffolding; Carter-Ching & Kafai, 2008; Hmelo, Holton, & Kolodner, 2000; Wood, Bruner & Ross, 1976). Facilitator-, peer-, and paper-based scaffolding prompts learners to consider new problem-solving strategies and reminds them of the strategy when they need assistance during the inquiry project (Reiser & Tabak, 2014). Additionally, technology-based scaffolding, as suggested by Quintana *et al.* (2004), can help scaffold complex concepts to build on the learner's intuitive understanding. We apply and adapt these scaffolding approaches to WBI, specifically in supporting the scientization of everyday activities with wearable sensors (Clegg & Kolodner, 2014; Metz, 2004; NRC, 2012).

Method

Through a design-based research approach (Sandoval & Bell, 2004), we iteratively designed tools, activities, and scaffolds to support children's learning about body systems and scientific inquiry through WBI experiences. In both 2016 and 2017, we partnered with three elementary public-school teachers. In each teacher's class, we conducted four, one-hour sessions of our wearable-based learning program with LPSV tools (BodyVis and SharedPhys; Table 1). To understand the range of elementary-aged children's experiences, we analyzed cases from two of the three classes—the youngest group (first-grade) and the oldest group (fourth-grade). We present a case study of the 2016 deployment (45 learners) followed by an analysis of and updates to our scaffolds, which we analyzed as an additional case study in the 2017 deployment (45 learners). Both sequences were conducted at the same public elementary school in the Washington, DC metro area (68% African American, 23% Hispanic/Latino, 3% Asian, 2% Caucasian, 4% Mixed Race; 65.6% free and reduced-priced meals).

We designed the initial learning activities, materials, and scaffolds of our 2016 deployment to align with NGSS (2013). Before implementation, we solicited feedback from our teacher partners. After the 2016 deployment, we conducted a participatory design session (Fails, Guha, & Druin, 2013) with the teachers to design the 2017 deployment. The result yielded new learning activities and goals, assessments, and facilitation plans that

Table 1: High-Level Description of Learning Activities for First- and Fourth-Grade Classrooms Deployment

Day	Session Activities for both 2016 and 2017
1	Learners used BodyVis to identify organs in the body and to conduct group inquiry with the heart and breathing rate functions. Facilitators solicited learners' questions about anatomy and physiology.
2	Facilitators led semi-structured activities in which learners used SharedPhys to conduct experiments.
3	Using their testable question from the previous day, learners designed procedures, crafted a hypothesis, and ran a trial of their procedures. Each group recorded their experiment on a sheet of chart paper.
4	Learners conducted their experiment, interpreted results, and presented findings to the class.

enhanced alignment with both NGSS (2013) and NRC inquiry standards (2012). We collected audio, video, and prototyping artifacts from participatory design sessions with the teachers as well as post-session notes.

For the case studies specifically, we analyze changes among the authenticity of the WBI small group projects and the influences of our redesigned scaffolds from 2016 to 2017. In each case, we observed five groups across two classrooms: three first-grade groups and two fourth-grade groups. For each group, we collected video and audio data, photographs, and inquiry project artifacts (*e.g.*, easel pad paper, drawings, worksheets). We also performed post-study interviews with the teachers to better understand their perspectives of WBI tools and learning activities and to solicit design suggestions. All interviews were transcribed.

Our data analysis is based on the NGSS (2013) and Chinn and Malhotra's (2002) framework for authentic scientific inquiry which breaks the scientific inquiry process into components (*e.g.*, asking questions, developing hypotheses) and describes each in terms of simple-to-authentic scientific inquiry. Using this framework, we designed a codebook to help us identify, for example, how and when students discuss controlling variables and instances in which children discussed their data (NGSS, 2013), as well as the roles of different environmental actors (*e.g.*, facilitators, peers). We then deductively coded video and audio of small groups conducting inquiry projects (Saldaña, 2015). Two researchers independently coded the same videos for one 2016 group, then met to discuss disagreements and clarify code definitions. For the remaining videos, researchers selected and coded videos of a random sampling of two to three groups across classrooms. This process was repeated for 2017. Coders then discussed and summarized major themes.

Teacher interview transcripts and the audio and artifacts of the teacher design session were structurally coded by topic (*e.g.*, design suggestion for learning activities, classroom ecosystem; Saldaña, 2015) by two researchers. After discussion, the researchers did a second round of coding to identify themes (Saldaña, 2015), and then synthesized the themed data for the larger research team to review. We compiled our summaries and findings into two cases (one for 2016, one for 2017) and performed axial coding to identify themes across groups by year (Saldaña, 2015). By grouping themes by year, we could look across the two iterations to identify differences in how learners designed and conducted their WBI projects. Our cross-case analysis thus considers the ways our iterated scaffolds (Table 2) influenced the learners' authentic inquiry experiences.

Findings

We present six themes regarding struggles learners faced in 2016 that we addressed with scaffolding changes in 2017. First, a vignette from our 2016 case illustrates the identified challenges. Then, we provide a description of the themes and map the scaffolding changes to ways in which learners' WBI projects changed in 2017 with respect to scientific authenticity. We demonstrate the influence of these scaffolds by presenting two 2017 vignettes, which illustrate the impact of the scaffolding across grades and spread among facilitators, peers, and materials.

2016 deployment findings

In 2016, first-and fourth-graders were engaged with their inquiry projects and could follow the facilitator's directions, however, they needed scaffolding to conduct WBI projects and not merely play with the LPSV tools.

On Days 3 and 4, first-grade Group B's assigned facilitator explained how to conduct a scientific experiment, facilitated their brainstorming and decision making, and assisted them in recording their ideas. Sitting in a circle, the facilitator began the experience by asking each learner to share a question they wanted to test with the LPSV tools. Learners struggled to either think of or share ideas on the spot. They instead silently reached for markers to draw on chart paper. When they did share, learners discussed *how* the physical activity would be done instead of the impact on their heart rate (*e.g.*, addressing who could run the fastest instead of the impact of running on heart rate). Often these ideas could not be tested with the LPSV tools or within the classroom. The burden was on the facilitator to determine what was testable, but she did not share her criteria. For example, when a child asked to measure the heart rate of their pregnant teacher, the facilitator said no but did not explain her rationale. Instead, she gave suggestions for questions, one of which the group selected to test (*e.g.*, the impact on heart rate when running across the room). When the group conducted their experiment, they became so excited about which child would "win" (*i.e.*, have the highest heart rate) as displayed by verbal and physical cheering, they did not discuss the overall data trend.

Across groups, we observed limitations in the authenticity of learners' experiments that were exemplified by this group. First, learners struggled to *articulate their ideas* into a testable question without a facilitator to rephrase their ideas. The facilitator also did not reveal a rationale for guiding the group towards a particular question. Thus, while learners were excited by their ideas (*e.g.*, who could run the fastest), they overlooked how the LPSV tools could be used in experimentation. We also observed that children *struggled to interpret SharedPhys's visual line graph to make claims*. During the SharedPhys experiments, children often became so focused on those performing activities (*e.g.*, running) that they did not pay close attention to the live data visualization—which only showed the last one-minute of data and could not be paused. This became a challenge when attempting to draw conclusions because children could not actively refer to the graph during discussions.

After the experiments, students *did not make theoretical claims*, rather they observed without asking why or discussing the connection between physiology and their WBI projects. The burden was on facilitators to connect the experimental results to the human body. All scaffolding was provided by *just-in-time facilitation* in the form of question prompts, reminders about next-steps, and feedback about learners' ideas for experimental questions or procedures. We recognize that this high-touch facilitation model would likely be intractable in a typical classroom where student-to-teacher ratios are much higher. Though the above vignette focuses on first-grade, we identified similar issues in the fourth-grade class; however, we found that fourth-graders were more comfortable in developing hypotheses and, with facilitator support, interpreting line graphs.

Iterating scaffolds for 2017 deployment

Given our 2016 deployment findings, we iterated our scaffolds to support more authentic WBI experiences and to reduce adult facilitation requirements. First, we reviewed the NGSS on how elementary learners should be conducting experiments. We then partnered with our teachers to design facilitation prompts and materials. Our analysis of teacher interviews and design ideas identified six key themes:

Constrain research questions to a set of testable criteria. In 2016, it was apparent that learners misunderstood the constraints of the LPSV tools by suggesting questions that moved outside of the classroom, were untestable within the time limit (*e.g.*, sleeping), or otherwise problematic (*e.g.*, taking poison). In 2017, we presented learners with a visual guide (Figure 2a) and testable question criteria (Table 2). Learners were then asked to self-check their questions with these criteria.

Vocabulary definitions (e.g., increase, decrease) for language to express ideas in a testable frame. In 2016, we observed that learners struggled to put words to their science questions and hypotheses. In 2017, we introduced an active learning vocabulary lesson and posted the words on the wall for the duration of our deployment (Figure 2b). In addition, we provided the first-graders with worksheets containing a word bank and

Table 2: Comparison of 2016 and 2017 Scaffolds for First- and Fourth-Grade Classrooms Deployment

Scientific Inquiry Stage	2016 Scaffolds	2017 Scaffolds with Developmentally-Appropriate Scaffolds by Grade
Question Development	Anatomy vocabulary lesson consisting of a large group discussion and scavenger hunt. Assigned facilitators assisted brainstorming and rephrased ideas into a testable format.	Both classes were provided with an anatomy and inquiry-related vocabulary lesson consisting of a class discussion, scavenger hunt, slideshow, and posters of words. Criteria were set for creating a testable question—the procedure for testing the question needed to be: conducted within one minute, conducted in the classroom with available materials, and measurable with an LPSV tool. First-graders were also provided with embodied definitions, a word bank on all worksheets and an assigned a facilitator who used sentence framing cards to aid learners to rephrase their ideas. Fourth-graders collaborated through online writing activities.
Procedure Design	Assigned facilitators led discussion and poster recording.	Both classes were provided with a chart paper with empty boxes with headings for each stage of the inquiry process. First-graders used a graphic organizer worksheet to draw and annotate ideas before facilitated discussion. Fourth-graders had access to floating facilitators for feedback.
Data Interpretation	Conducted experiments as a class on Day 2.	During Day 2 large group experiments, facilitators taught embodied methods of analyzing changes in SharedPhys' visualization. First-graders practiced interpreting line graphs by drawing their hypotheses for the worked example and comparing it to the results.
Theory Building	Facilitators led large-group discussions.	Facilitators synthesized findings after experiments were conducted and led a large group discussion. First-graders were provided with a poster on which the facilitators recorded the results of all experimental findings.

sentence structure cue cards. We also taught first-graders *embodied* definitions (*i.e.*, Total Physical Response; Asher, 1969) for words beyond the NGSS (*e.g.*, circulatory system). These body movements ground complex physiology content in gestures and meanings familiar to children (Lee, 2015).

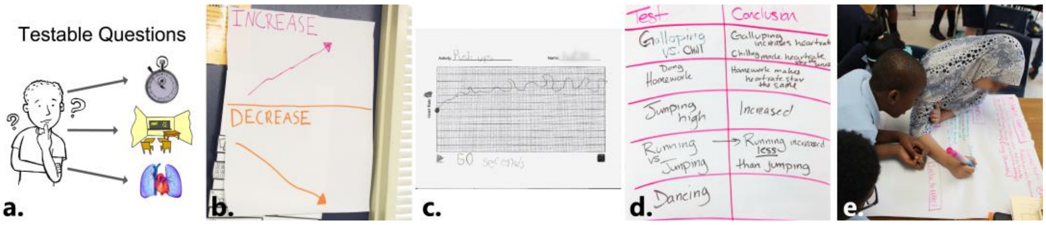

Figure 2. WBI Scaffolds: (a) testable question criteria, (b) vocabulary posters, (c) paper-based drawing worksheets, (d) experimental findings posters, and (e) large chart paper with a WBI template.

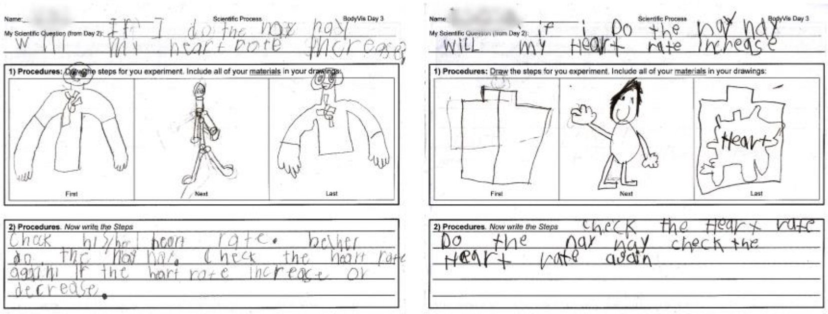

Figure 3. First-Graders' drawings of procedure ideas.

Grade-specific writing activities to aid idea expression and procedural thinking. Noting how learners of both grades struggled to develop questions and experimental procedures, we designed writing activities to reduce the burden on the facilitators. As recommended by the teachers, we took a grade-specific approach. We provided first-graders with a three-panel graphic organizer worksheet on which they could draw and write before being asked to verbalize their ideas (Figure 3). Graphic organizers guided learners to make chronological sense of the procedures by having them describe steps in order. By using drawing instead of text to explain abstract ideas, we bridge the learner's intuitive understanding of complex concepts to the inquiry process (Quintana *et al.*, 2004). For the fourth-graders, learners collaboratively brainstormed research questions, shared knowledge, and remixed each other's ideas through online collaborative writing activities (in Google Docs). The fourth-graders discussed their ideas and received peer feedback.

Opportunities to practice prediction and interpreting line graphs. In 2016, we found that while fourth-graders could develop hypotheses and interpret line graphs, first-graders struggled to connect the SharedPhys visualization to their abstract understanding of physiology. In 2017, we scaffolded hypothesis development by including discussions, embodied interpretation (*e.g.*, using their arms to trace the line in the air; Asher, 1969), drawing, and recording after each experiment. Realizing their need to doodle or draw their understanding before discussing it, we asked first-grade children to imagine performing an activity and then draw a prediction of their heart rate on graph paper resembling the SharedPhys screen (Figure 2c). We facilitated discussions on learners' graphs and corrected misinterpretations (*e.g.*, Maya is the blue line, Ed is the green line). We encouraged children to use embodied definitions of *increase* and *decrease* by physically acting out their predictions (Asher, 1969). Using paper arrows, we posted the learners' predictions onto the SharedPhys screen before learners wearing the sensors (*i.e.*, wearers) did the activity. During the experiment, the class could observe how the real-time heart rates change compared to their prediction heart rates. Finally, we asked wearers to describe what their heart rate felt like. Wearer testimonials and SharedPhys results were then compared to the predictions.

Synthesis of results across groups for collective understanding and building theory. To bridge connections across experiments and reaffirm understanding, facilitators rephrased the findings of each experiment after the class had drawn their own conclusions and supported learners in theory building in a way that was developmentally-appropriate. In 2016, first-graders often could not state the findings of a past experiment. So, in 2017, facilitators recorded each first-grade group's experimental findings on a large poster so that learners could see and reference prior findings (Figure 2d). Fourth-graders were better able to remember prior findings in discussions but facilitators helped them to synthesize data from across the experiments into a theory.

Visualization of the inquiry process so that learners are aware of next steps. In both years and in both classes, small groups were given markers and large chart paper (Figure 2e) to record their names, research question, hypotheses, procedures, heart rate data, and findings. In 2017, however facilitators drew boxes on the chart paper corresponding to the stages of WBI for learners to fill-in. This template was meant to guide learners through the WBI process by revealing what they needed to complete and record at each stage.

2017 deployment findings

In 2017, we observed that with our iterated scaffolds, early elementary learners needed less high-touch facilitation to develop a testable question and procedures, and accurately interpret visualized data into evidence-based theory. They still needed more facilitator guidance, however, when synthesizing results across experiments. To demonstrate the impact of our scaffolds, we present two vignettes:

Vignette 1: First-graders investigating the effect of the Nae-Nae dance on the body

After providing learners with testable question criteria, they brainstormed activities that were personally meaningful and met the provided criteria. One boy, Alex, shared his excitement to test dancing because of his love of dancing—especially doing the Nae-Nae. The facilitator, Omar, asked the group for feedback and they agreed to investigate the impact of doing the Nae-Nae dance on their heart rate.

The three-panel drawing worksheet allowed learners to externalize abstract ideas into a sequence of drawings and annotations (Figure 3). Without facilitation, many students used the three panels to draw a sequence of observation – action – observation. Omar presented learners with sentence structure cue cards with ideation and sentence framing words (e.g., If, Then) to enable them to format their ideas into a procedure for investigating causal relationships. These cards did not appear to be impactful, however, because the learners paid little attention to the cards and continued to draw their ideas. After drawing and writing on their individual sheets, the children shared their ideas, formalized their procedure, and wrote it in the inquiry template on the large chart paper.

As a class, each group conducted their experiment and Omar used the poster (Figure 2d) to visually display each group's findings. We observed that learners referred more to past findings to make claims than in prior years, often while looking at or pointing to the visual repository. This visual repository made it easier for learners to refer to past findings to make claims and for Omar to bridge together findings to pose theories. After the Nae-Nae experiment, Omar wrote "*increased a little*" because the class concluded that the dancing increased the wearers' heart rate but not to the same extent as some prior activities. After all experiments were done, Omar had the class refer to their poster of results to synthesize their findings into a theory (*e.g., "activities like running and galloping lead to a bigger increase in heart rate"*). When asked what they learned, children volunteered new theories (*e.g.,* when you exercise big muscles like the legs, they need more oxygen and so your heart beats faster), which helped demonstrate their grasp of the relationship between physiology and activity.

Vignette 2: Fourth-graders investigating the effect of being scared on the body

In the fourth-grade class, facilitators floated between groups instead of being assigned to a group as in the first-grade class. Group A needed facilitator attention because they could not agree on a physical activity to test. The facilitator, LaSonya, in trying to mediate the group tension, talked about how emotional reactions (*e.g.,* laughing, feeling scared) also impact our heart rate. After some debate, the group decided to test how being scared affects heart rate. Group A's conversations focused on completing each section of the chart paper WBI template and imagining how much their idea would impress their peers. Without prompting, Group A identified ideas that were not testable (*e.g.,* "*Seeing a scary movie would take too much time*"). Group A's ideas for how to scare someone were shared as personal stories from when they remembered being scared (*e.g.,* "*We should do the thing my sister did…*"). They generalized from life experiences when they were most scared and developed a list of ways to scare the wearers. The group was able, then, to narrow this list based on what fit the testable criteria.

For their SharedPhys experiment, the group tested three scare tactics (*e.g.,* being poked, grabbed, and screamed at) and observed the wearer, Janet's, resulting heart rate. In response, however, Group A's classmates had concerns about the validity of the experiment. They questioned if the increase in heart rate was caused by Janet jumping or laughing instead of being scared (*e.g.,* "*She was laughing which got her heart rate up*"). Group A was also skeptical of the accuracy of the SharedPhys data and voiced concern that they could not identify on the graph when each scare tactic was implemented.

2017 case summary

These vignettes illustrate how learners asked life-relevant, testable questions and developed their own experimental procedures. Our findings suggest that providing testable question constraints lessened the complexity of asking inquiry questions and planning procedures for learners (Quintana, et al., 2004) while also offering freedom to explore life-relevant investigations. This was evident in our observations of learners using the testable criteria to discuss and decide among themselves which ideas and procedures were testable. Our analysis of first-graders' discussion contributions and drawings suggests that learners in our 2017 case had a clearer understanding of how to interpret the visual line graphs in SharedPhys. We attribute their increased interpretation of line graphs to the drawing scaffolds in which learners mapped their own visual hypotheses to the real-time results visualized on SharedPhys (Figure 2c). Lastly, after conducting the embodied experiments, first-grade students made theoretical claims about the connection between physiology and physical activities–a key component of the Chinn and Malhotra (2002) framework that we did not see in the 2016 case. We did not observe a difference in how fourth-graders across both years developed theories across experiences, suggesting that the LPSV tools and 2016 activities were enough to help them make connections to physiological phenomena. While facilitators still had to help learners develop questions and procedures in their small groups in 2017, they were able to make use of paper-based scaffolds (*e.g.,* chart paper, worksheets) that reduced the burden on how much help they needed to provide to each group. Facilitators provided more scaffolding in 2017 during whole group conversations for recording observations and synthesizing results across experiments.

Discussion

Although some prior work in WBI notes the importance of scaffolding children's use of technology for inquiry (*e.g.,* Lee, Drake & Williamson, 2015), we provide the first examination of the impact of scaffolds on the inquiry process. Through our iterative design process, we considered how multiple dimensions of scaffolds (*i.e.,* tools, peers, facilitators, and paper-based materials) could be integrated to support early-elementary learners' WBI. By integrating *facilitation-based scaffolds, paper-based scaffolds* (*e.g.,* the prediction drawing worksheet), *peer-based scaffolding,* and the *wearable tools* themselves, we found that learners could test and accurately interpret investigations of two types of questions. First, changes in heart rate over time (*e.g.,* change in heart rate when doing the Nae-Nae dance for a minute) and, second, changes in heart rate across learners or activities (*e.g.,* change in heart rate for three different scaring tactics). Paper-based scaffolds bridged facilitator- and peer-based scaffolding so that after some guidance, peers could support each other, compare drawings, and self-check the feasibility of an idea. When learners supported each other in groups, facilitators could focus on synthesizing past findings on large sheets of paper, which learners referred to when trying to generalize across experiments. This theory building process is a key component of Chinn and Malhotra's framework (2002) and the NGSS (2013).

With respect to authentic inquiry, we found that, as in prior work with older children (*e.g.,* Lee & Drake, 2011; Lee & Thomas, 2011), early elementary learners could design and conduct life-relevant WBI by examining everyday activities (e.g., dancing, scaring, laughing). Although many of the WBI projects in our study included gym or recess activities like prior embodied WBI research (*e.g.,* Lee *et al.,* 2015), three of the five 2017 small groups we analyzed also included other activities such as homework and dancing. We found that, with our integrated scaffolds and LPSV tools, early learners explored the embodied connection between physical activity data and the physiological phenomenon of their bodies (*e.g.,* the circulatory system). Beyond the scope of prior WBI studies, which emphasized interpreting trends in visualized data (*e.g.,* Lee & Thomas, 2011), learners in our study recognized the physiological impacts of stress and fear. Our multi-dimensional scaffolds supported learners' exploration of their physiological functioning and ability to relate findings back to their own everyday activities.

We also observed limitations in our current scaffolds. We found that despite our integration of differing scaffolds, first-graders still needed facilitator help with literacy-based aspects of the inquiry process (*e.g.,* articulating questions and evidence-based claims). Future research is needed to further enhance such scaffolds for WBI. Additionally, as is common among design-based research studies with multiple sources of data, we had to exclude some details of our study that would have been included in a longer article. Finally, our vignettes represent some of the more life-relevant WBI projects. Half of the groups in each class tested comparisons of physical activities (*e.g.,* galloping, lunges). We therefore need additional scaffolds to help learners more systematically develop creative questions unique to their specific interests and experiences.

Our findings contribute to how educators can implement wearable sensors for inquiry and embodied learning in early elementary classrooms and more broadly, how educators can use sensor-based learning to meet NGSS (2013). Our work differs from and expands on prior WBI work by focusing on early-elementary learners, iterating and comparing inquiry scaffolds across two deployments, and working with teachers to explicitly align with NGSS. While we found that a multi-dimensional scaffolding approach can support early learners in planning and conducting authentic WBI, more work is needed to understand how peer scaffolding can be leveraged to lessen the burden on educators so that WBI is more realistic to the typical student-teacher ratio.

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Acknowledgments
This work was supported by NSF Grant (IIS-1441184). We thank the participating children and teachers.