Designing Wearable Technologies, and the Experiences Around Them, for Children's Body Learning

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Research Interests

Wearable Technology

Children's Education Technology

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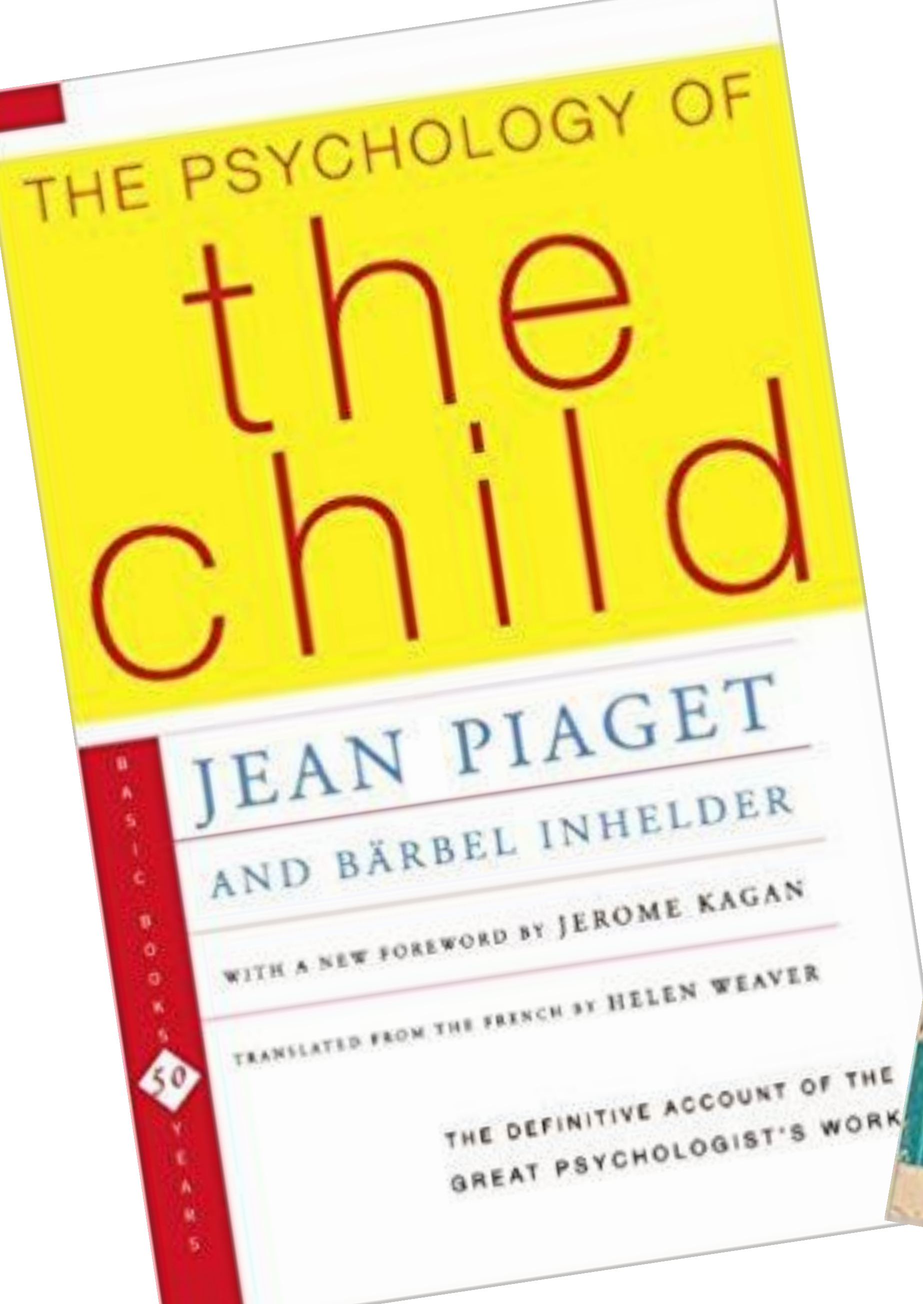
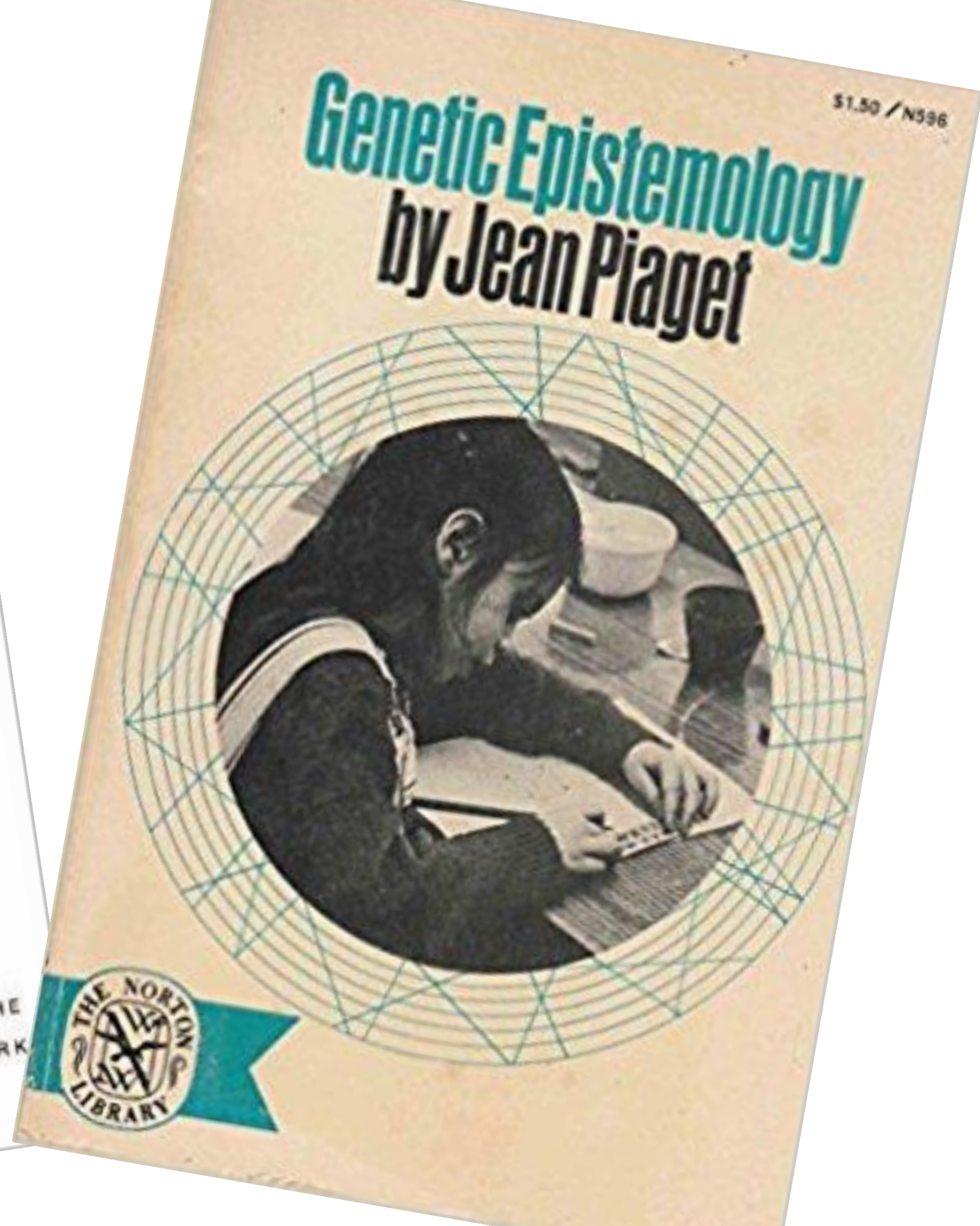
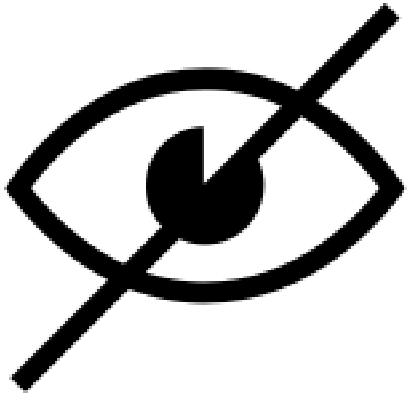




Piaget, J. & Inhelder, B. *The Psychology of the Child,* 1969
Piaget, J. & Duckworth, E. *Genetic Epistemology,* 1970

Understanding abstract information is hard for children because they cannot:

See the information



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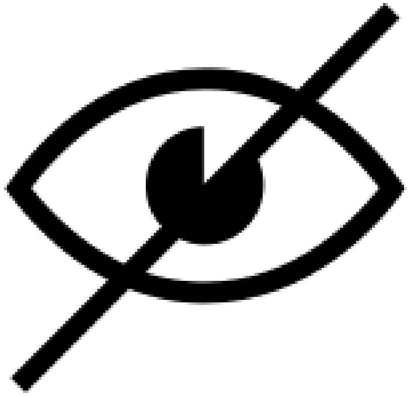
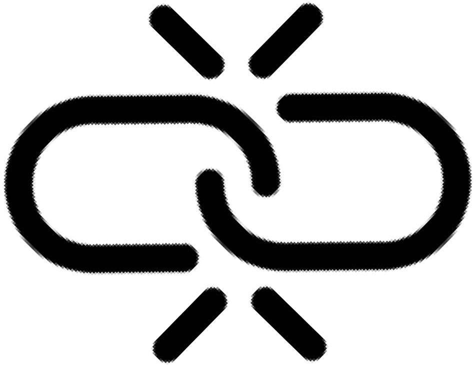


Connect abstract concepts to everyday life experiences



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Many Science, Technology, Engineering, and Math **(STEM)** topics are abstract

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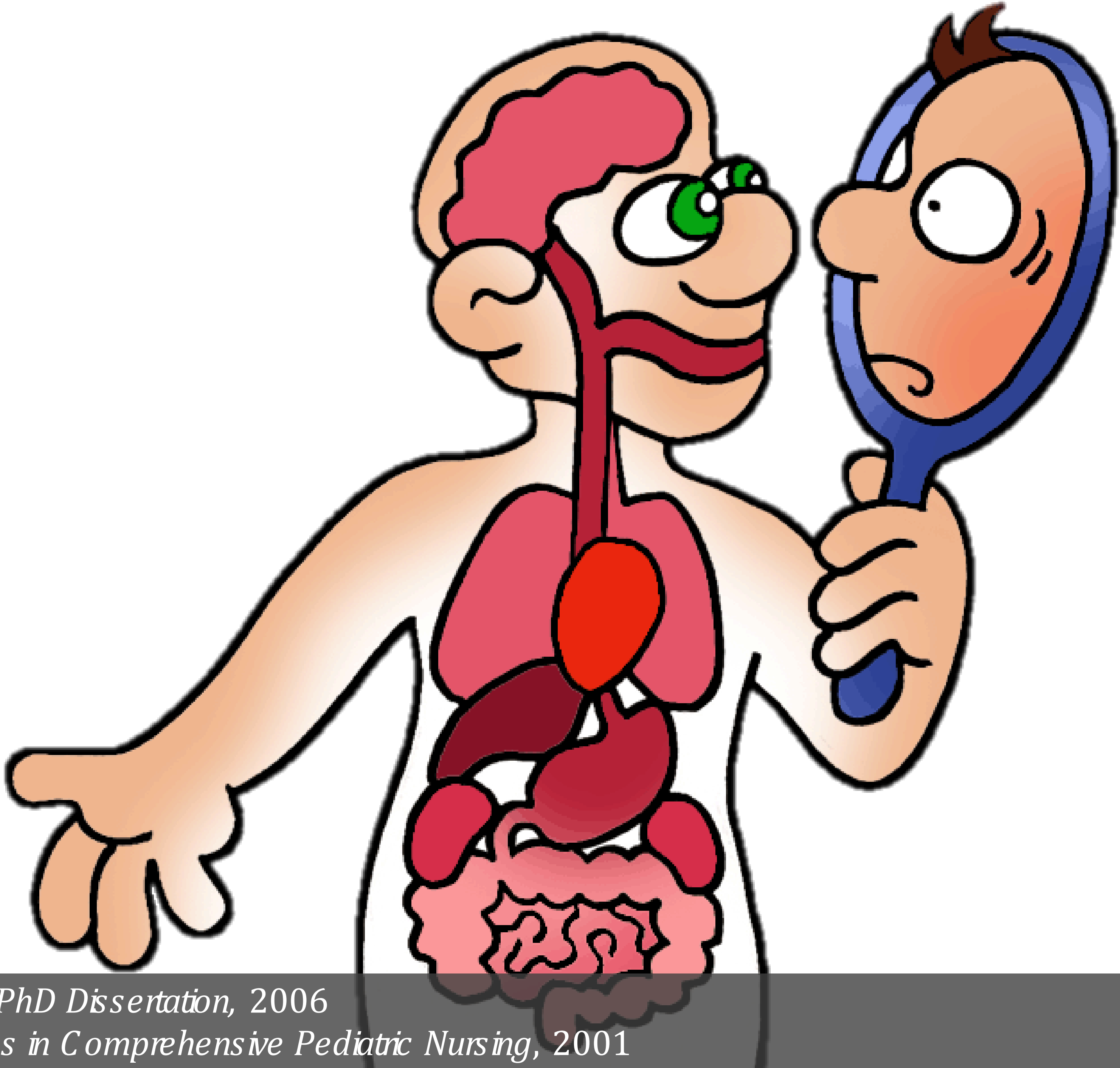
Children find them boring, irrelevant, and disconnected from their lives



Óskarsdóttir, G. *PhD Dissertation*, 2006
Schmidt, C.K. *Issues in Comprehensive Pediatric Nursing*, 2001

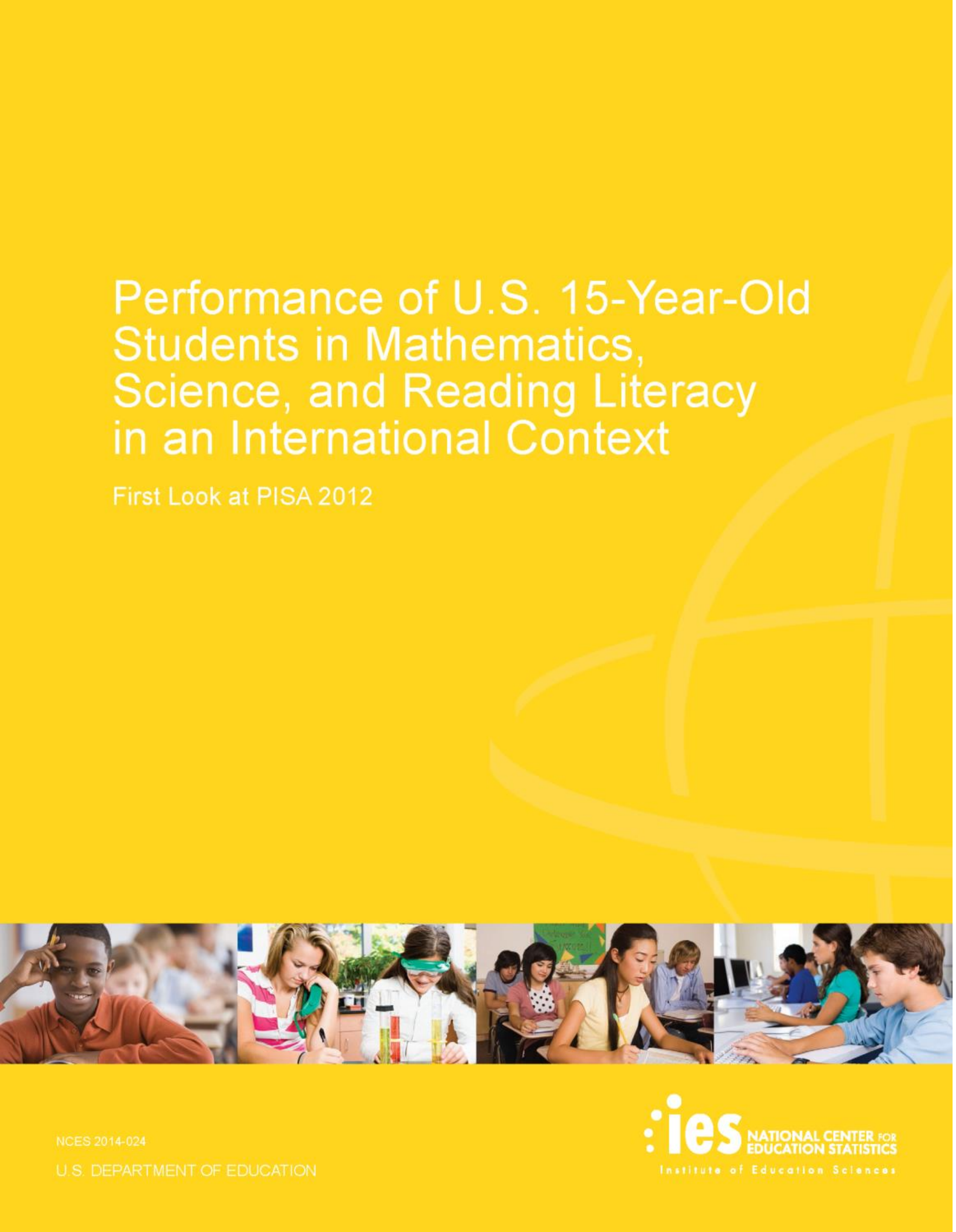
Performance of U.S. 15-Year-Old Students in Mathematics, Science, and Reading Literacy in an International Context

First Look at PISA 2012

NCES 2014-024

U.S. DEPARTMENT OF EDUCATION

NATIONAL CENTER FOR EDUCATION STATISTICS
Institute of Education Sciences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ies NATIONAL CENTER FOR EDUCATION STATISTICS

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Students in the United States are falling behind in STEM achievements, resulting in a need for new methods of learning STEM topics.

Program for International Student Assessment (PISA), 2012

NEXT GENERATION
SCIENCE
STANDARDS

PRACTICES
CORE IDEAS
CROSSCUTTING

NEXT GENERATION SCIENCE STANDARDS

"…Help students build a **cohesive understanding of science** over time" by thinking and acting like professional scientists and engineers.

www.NextGenScience.org

Our Approach

MEDIUM:
Wearable Technology

FRAMING:
Anatomy & Physiology

Our Approach

MEDIUM:
Wearable Technology

Technology is integrating into the school environment

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On-body sensor-based learning, via wearable interfaces, help children explore, analyze, and visualize phenomena in STEM

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Can play a critical role in teaching other science topics (biology, math nutrition, systems, and matter and energy)

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Design considerations for wearables

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2 Help children make **life-relevant connections** with the information

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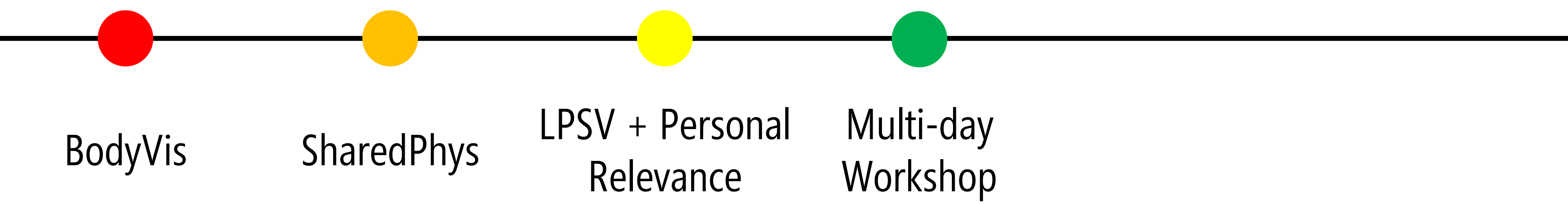

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BodyVis

SharedPhys

LPSV + Personal Relevance

Multi-day Workshop

Current Research

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BodyVis: A New Approach to Body Learning Through Wearable Sensing and Visualization

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ABSTRACT

Internal organs are hidden and untouchable, making it difficult for children to learn their size, position, and function. Traditionally, human anatomy (body form) and physiology (body function) are taught using techniques ranging from worksheets to three-dimensional models. We present a new approach called *BodyVis*, an e-textile shirt that combines biometric sensing and wearable visualizations to reveal otherwise invisible body parts and functions. We describe our 15-month iterative design process including lessons learned through the development of three prototypes using participatory design and two evaluations of the final prototype: a design probe interview with seven elementary school teachers and three single-session deployments in after-school programs. Our findings have implications for the growing area of wearables and tangibles for learning.

Author Keywords

Wearables; interactive body learning; physiological sensing

INTRODUCTION

Learning the position, structure, and function of internal body parts is challenging for children [29,30,35]. Unlike fingers, arms, toes, and other external parts, internal organs remain hidden beneath layers of skin, muscle, and tissue and operate without conscious thought, making it difficult for children—and even adults [3]—to understand the internal workings of their bodies. This body knowledge is important. For pre-school and primary school children, higher body literacy corresponds to greater compliance with health care regimens, better self-care practices, and increased self-understanding [30,33]. For example, young children with asthma are more likely to take inhaled medications if they understand how their lungs function [30]. Other researchers emphasize the critical role of anatomy and physiology in teaching and understanding basic science (*e.g.*, biology) [11].

CHI 2015, April 18 - 23 2015, Seoul, Republic of Korea

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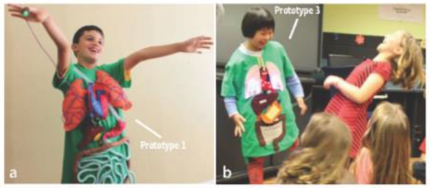

Figure 1: *BodyVis* is an interactive e-textile shirt for body learning that actively responds to the wearer's physiology and visualizes their body data on externalized anatomical models. Prototypes 1 and 3 shown above.

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In this paper, we present *BodyVis*, a custom-designed wearable e-textile shirt that combines biometric sensing and interactive visualization to reveal otherwise invisible parts and functions of the human body (Figure 1). The wearer's physiological phenomena are visualized on externalized fabric anatomy, allowing the wearer and viewers to gain a unique view of the internal body. While past research has investigated wearables [22,23,24] and augmented reality [2,4,26] for body learning, BodyVis is the first exploration of a physical/digital manifestation that actively responds to the physiology of the wearer.

To investigate our approach, we iteratively designed and evaluated three BodyVis prototypes over a 15-month design cycle. While our long-term aim is to assess how a BodyVis-approach may impact learning, as an initial investigation, our research questions were exploratory: *e.g.*, identifying key design considerations, exploring the understandability, aesthetics, and approachability of our prototypes, and examining how BodyVis *engages* children in body learning topics. Our design iterations were informed by two participatory design sessions with children, a MakerFaire exhibit, an early demonstration at a children and technology design conference (*IDC'13*) [27], and relevant prior work (*e.g.*, importance of 3D models in learning [31], idea of bio-responsive e-textiles [21]).

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BodyVis — SharedPhys — LPSV + Personal Relevance — Multi-day Workshop — Current Research — Future Work

What if our clothes revealed how our body functions?

How could this change the way children learn about and understand their bodies?

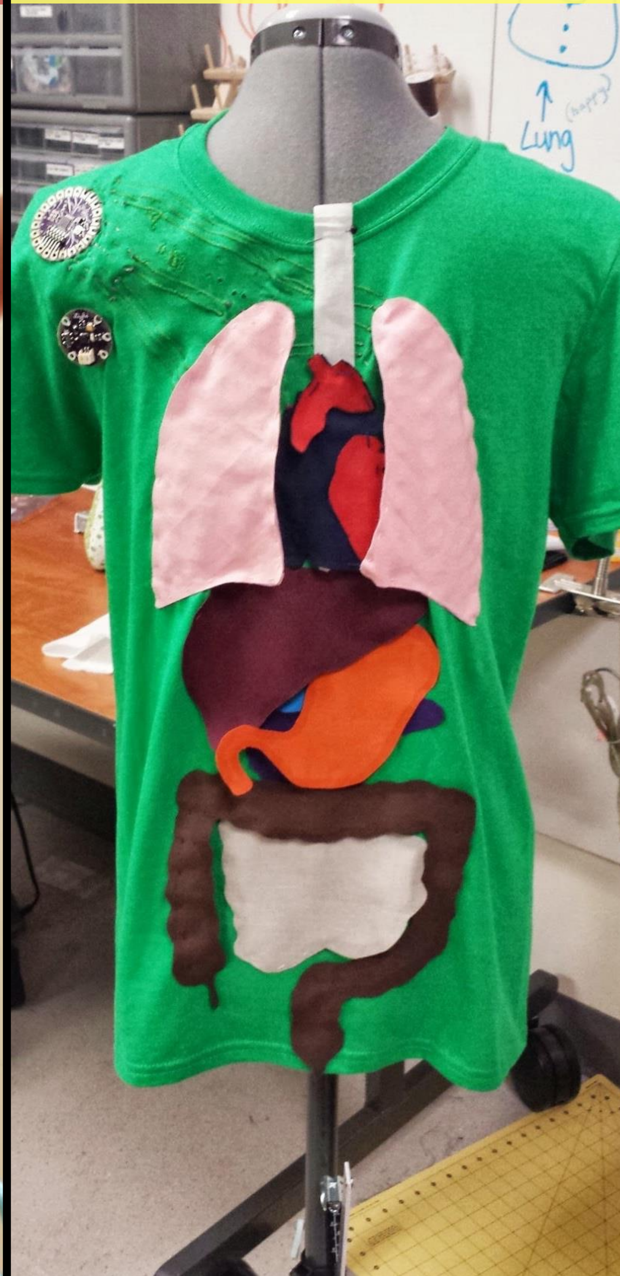
Could a t-shirt be a platform for experimentation and inquiry?

LIVE PHYSIOLOGICAL SENSING & VISUALIZATION

LPSV

Prototype 1
Plush, Colorful, Interactive

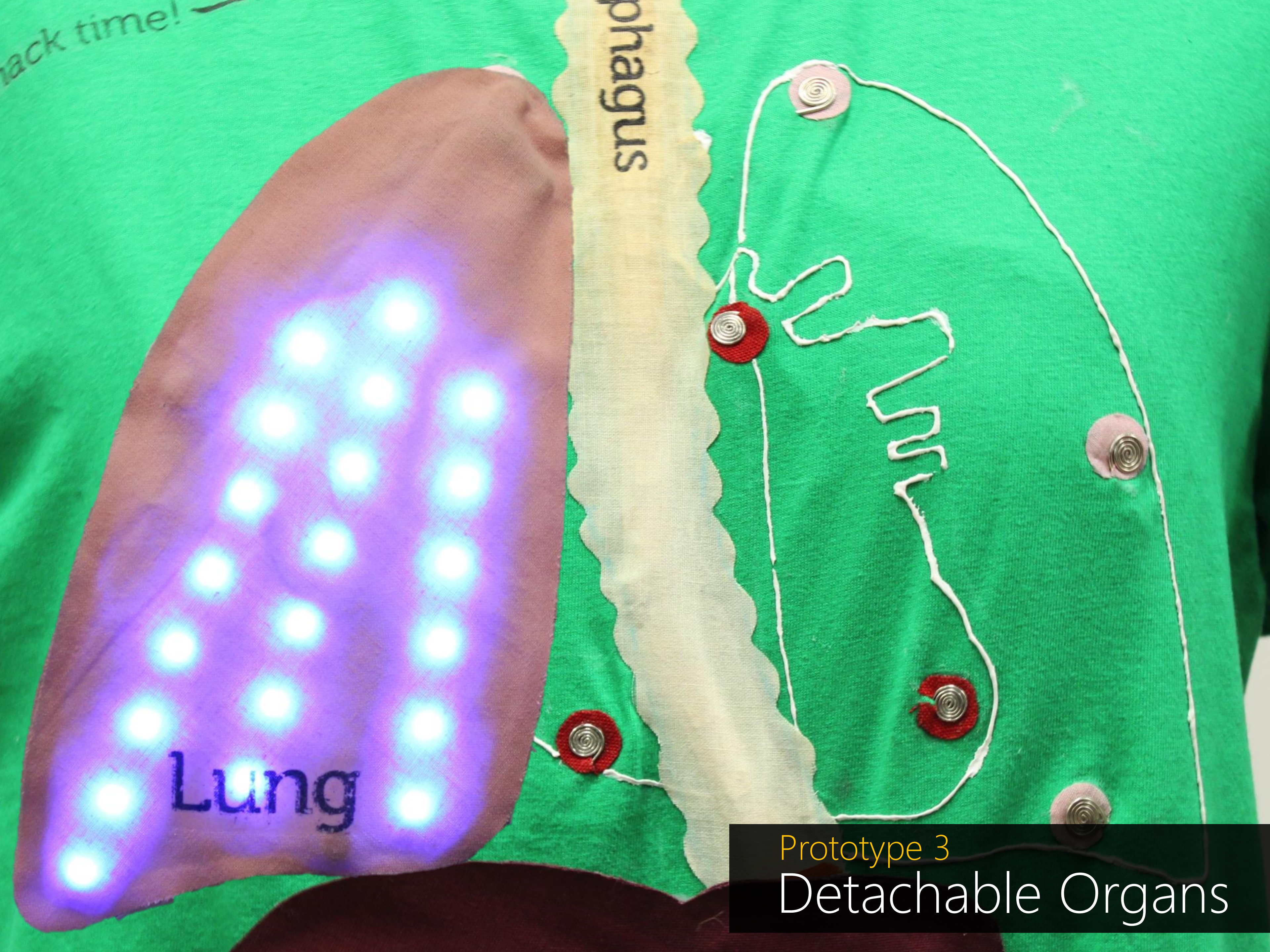
Prototype 2
A New Lightweight Design



Prototype 3
The Current Design

DESIGN/ARCHITECTURE


See Norooz et al.,
2015 for more
Heart Rate:
60 bpm
Breathing Rate:
15 bpm
Heart
Lung
Lung
Liver
Large Intestine
Small Intestine


Lung
Prototype 3
Detachable Organs


time!
sophagus
>>x3

BodyVis Usability Study

BodyVis

SharedPhys

LPSV + Personal Relevance

Multi-day Workshop

Current Research

Future Work

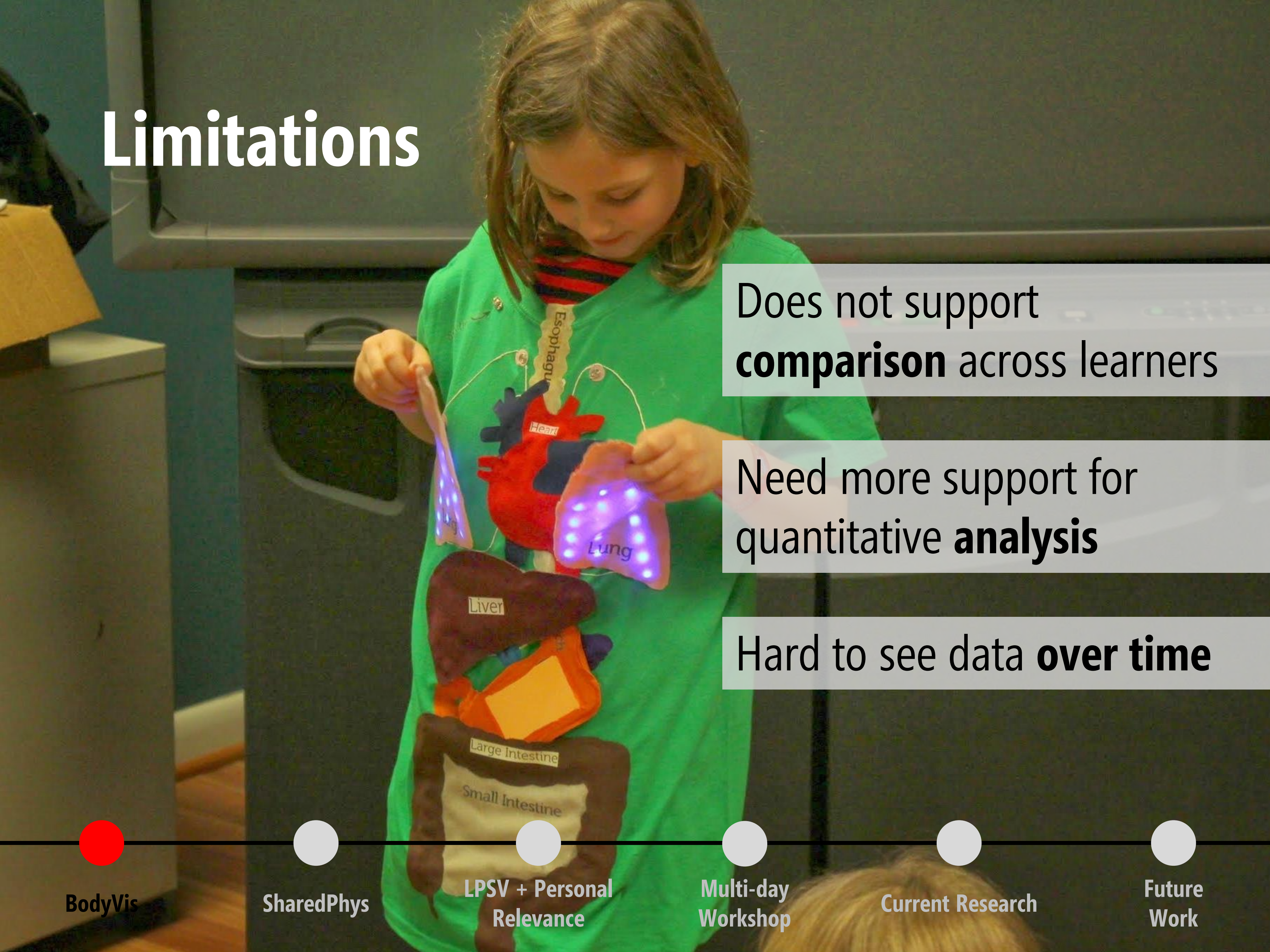
Findings

Wearers and non-wearers **worked together** to explore and play

Removable organs allowed for **exploration**

Promoted **inquiry questions** and observations

BodyVis — SharedPhys — LPSV + Personal Relevance — Multi-day Workshop — Current Research — Future Work



Limitations

Does not support **comparison** across learners

Need more support for quantitative **analysis**

Hard to see data **over time**

BodyVis — SharedPhys — LPSV + Personal Relevance — Multi-day Workshop — Current Research — Future Work

BodyVis

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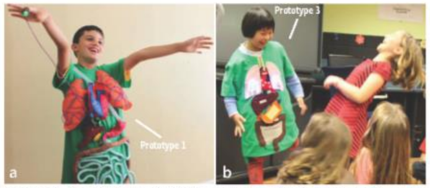

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SharedPhys

SharedPhys: Live Physiological Sensing, Whole-Body Interaction, and Large-Screen Visualizations to Support Shared Inquiry Experiences

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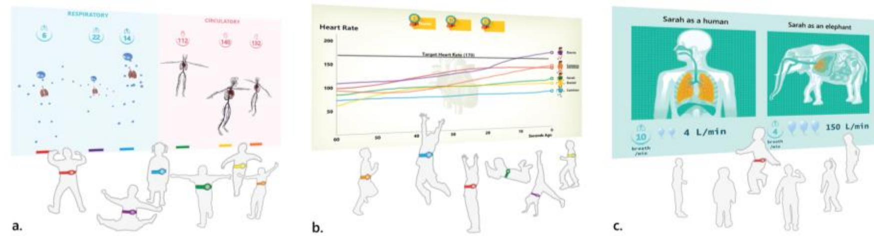

Figure 1: *SharedPhys* combines physiological sensing, whole-body interaction, and real-time large-screen visualizations to create new types of embodied interactions and learning experiences. Shown above, our three interactive SharedPhys prototypes: **(a)** Magic Mirror, **(b)** Moving Graphs, and **(c)** Animal Avatar.

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We present and evaluate a new mixed-reality tool called *SharedPhys*, which tightly integrates real-time physiological sensing, whole-body interaction, and responsive large-screen visualizations to support new forms of embodied interaction and collaborative learning. While our primary content area is the human body, we use the body and physical activity as a pathway to other STEM areas such as biology, health, and mathematics. We describe our participatory design process with 20 elementary school teachers, the development of three contrasting SharedPhys prototypes, and results from six exploratory evaluations in two after-school programs. Our findings suggest that the tight coupling between physical interaction, sensing, and visualization in a multi-user environment helps promote engagement, allows children to easily explore cause-and-effect relationships, supports and shapes social interactions, and promotes playful experiences.

Author Keywords
Physiological sensing; large-screen displays; mixed-reality; scientific inquiry; collaborative learning; STEM; wearables

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI).

INTRODUCTION
With the emergence of body-tracking technologies such as *Fitbit* and the *Microsoft Kinect*, there has been increased interest in exploring how *embodied interaction* [14] can enable and support new learning experiences [34]. Recent work by Lee *et al.*, for example, helps demonstrate the potential of wearable activity trackers and interactive visualizations to engage children in scientific inquiry that is authentic and life-relevant [36, 37]. Often citing the role of embodiment in cognition [56], others have explored utilizing the entire body through movement or gesture to support new forms of computer-mediated learning [31, 34]. Though a nascent area, research suggests that these whole-body interactions can help increase engagement [1, 62] and immersion [1, 69], support and shape social interaction [59, 69], and aid learning [31].

Building on the above work, this paper introduces and evaluates *SharedPhys*, which integrates live-streaming physiological sensors, whole-body interaction, and real-time large-screen visualizations to create a novel mixed-reality learning environment. With SharedPhys, children interact *physically*—both explicitly via body movement, gesture, and position as well as implicitly via their changing physiology. While prior work has explored body-centric inquiry (*e.g.*, [32, 36, 37]), the data collection and subsequent analyses are often disjoint and performed on a traditional computer setup. In contrast, our work simultaneously involves the body in data collection, interaction, and analysis creating new opportunities for feedback loops and playful experimentation. Similarly, while recent work has explored mixed-reality environments for collaborative learning, most have utilized simulations (*e.g.*, [12, 42, 47]) or artificial data (*e.g.*, [58]). Our work combines live streams of *real* body-data in a shared environment. We believe this tight coupling between physical action, physiological sensing, and live visualization offers new, rich possibilities for user interaction and learning experiences.

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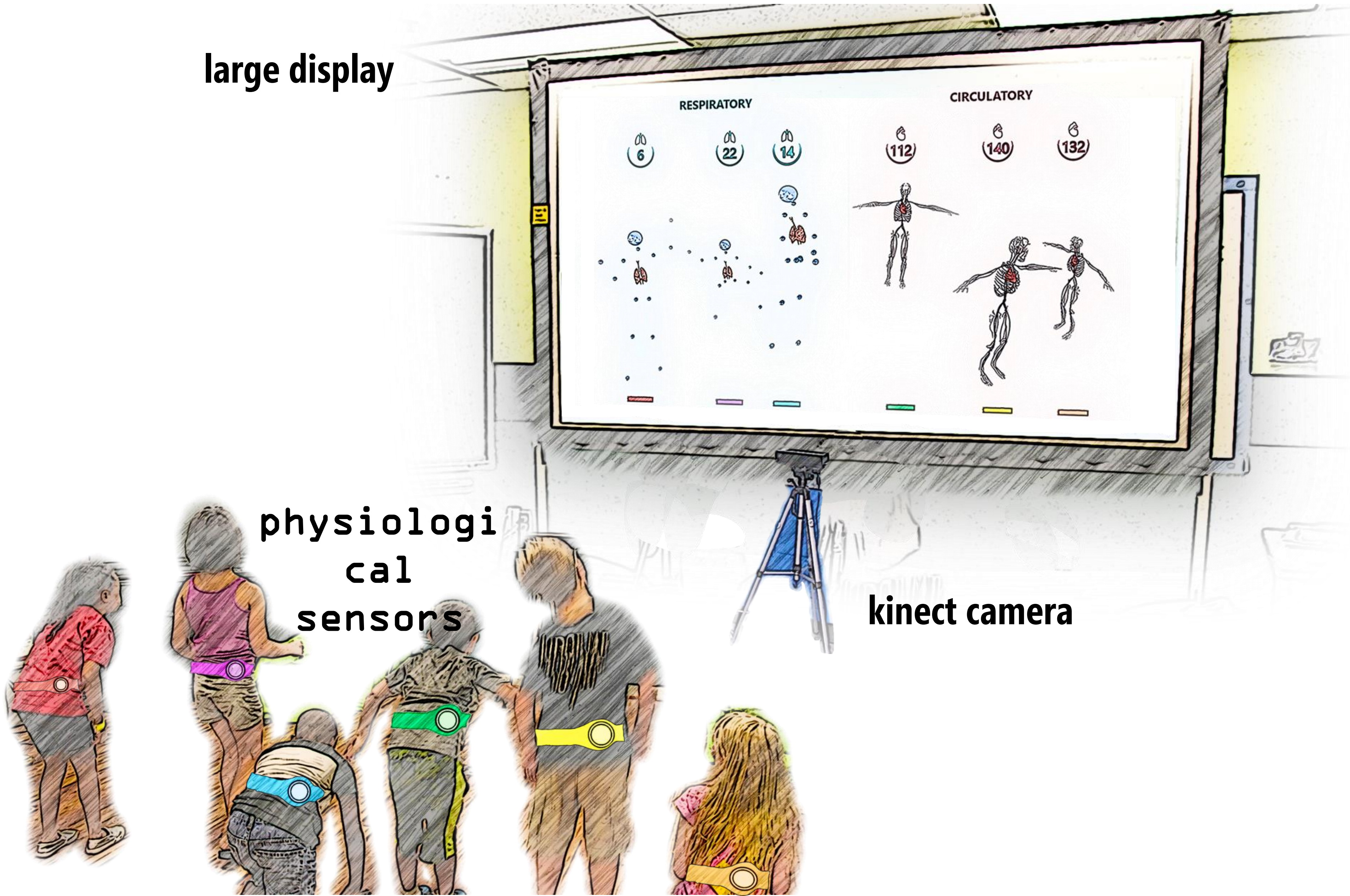
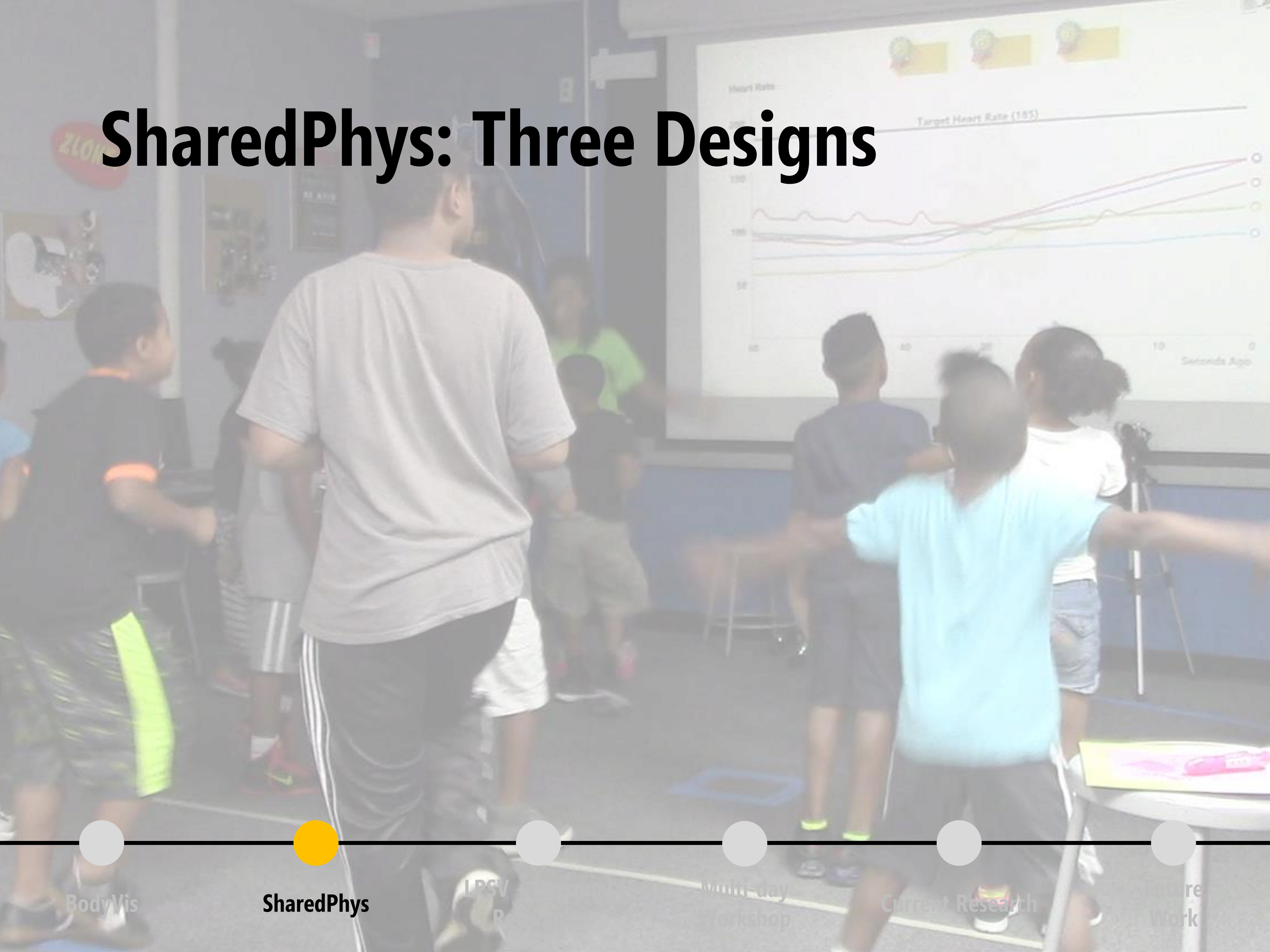
How can we **compare** and **analyze** bio-data **over time**?


large display
RESPIRATORY
CIRCULATORY
6
22
14
112
140
132
physiological sensors
kinect camera

SharedPhys: Three Designs



SharedPhys: Three Designs

Magic Mirror

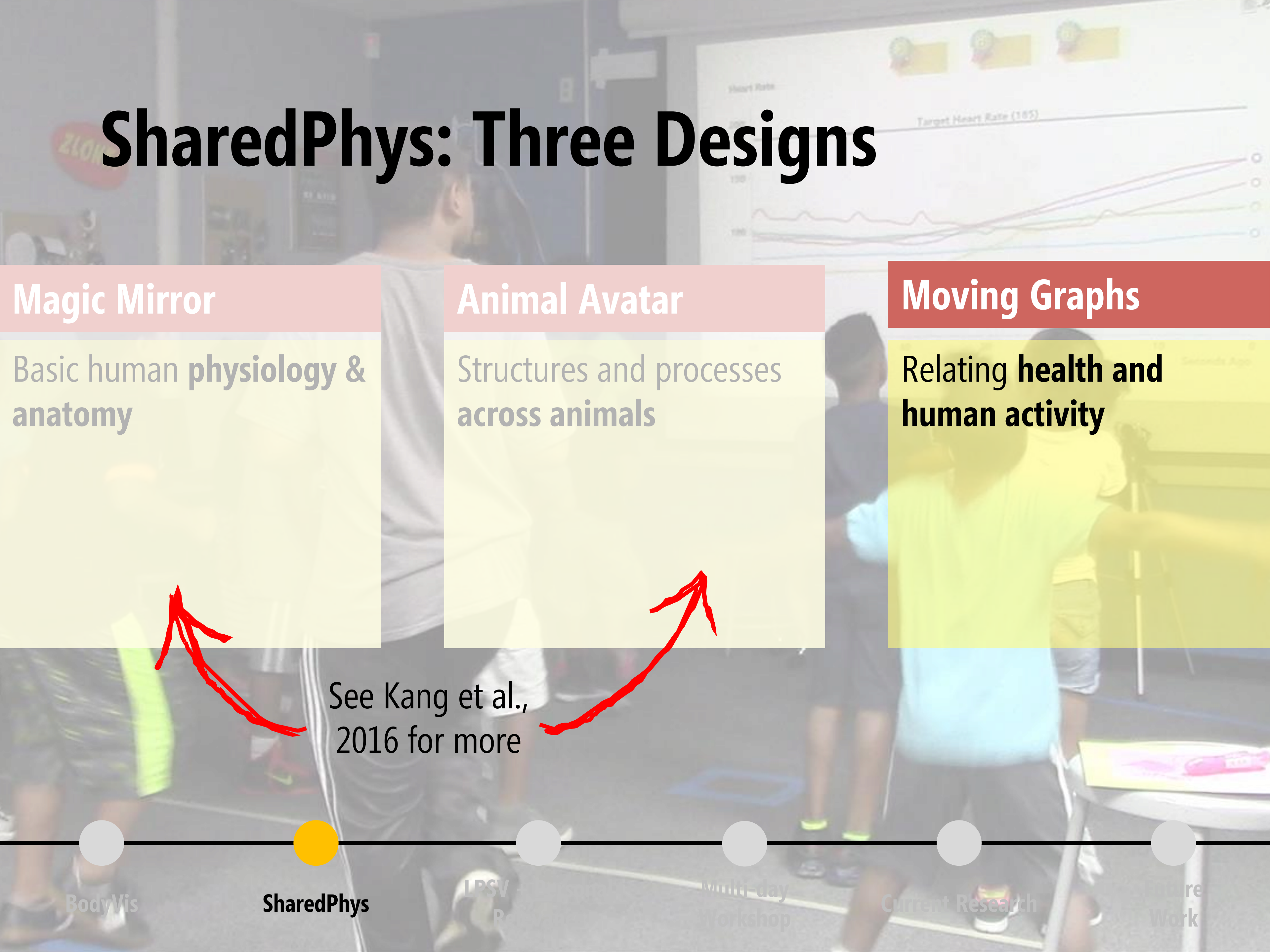
Basic human **physiology & anatomy**

Animal Avatar

Structures and processes **across animals**

Moving Graphs

Relating **health and human activity**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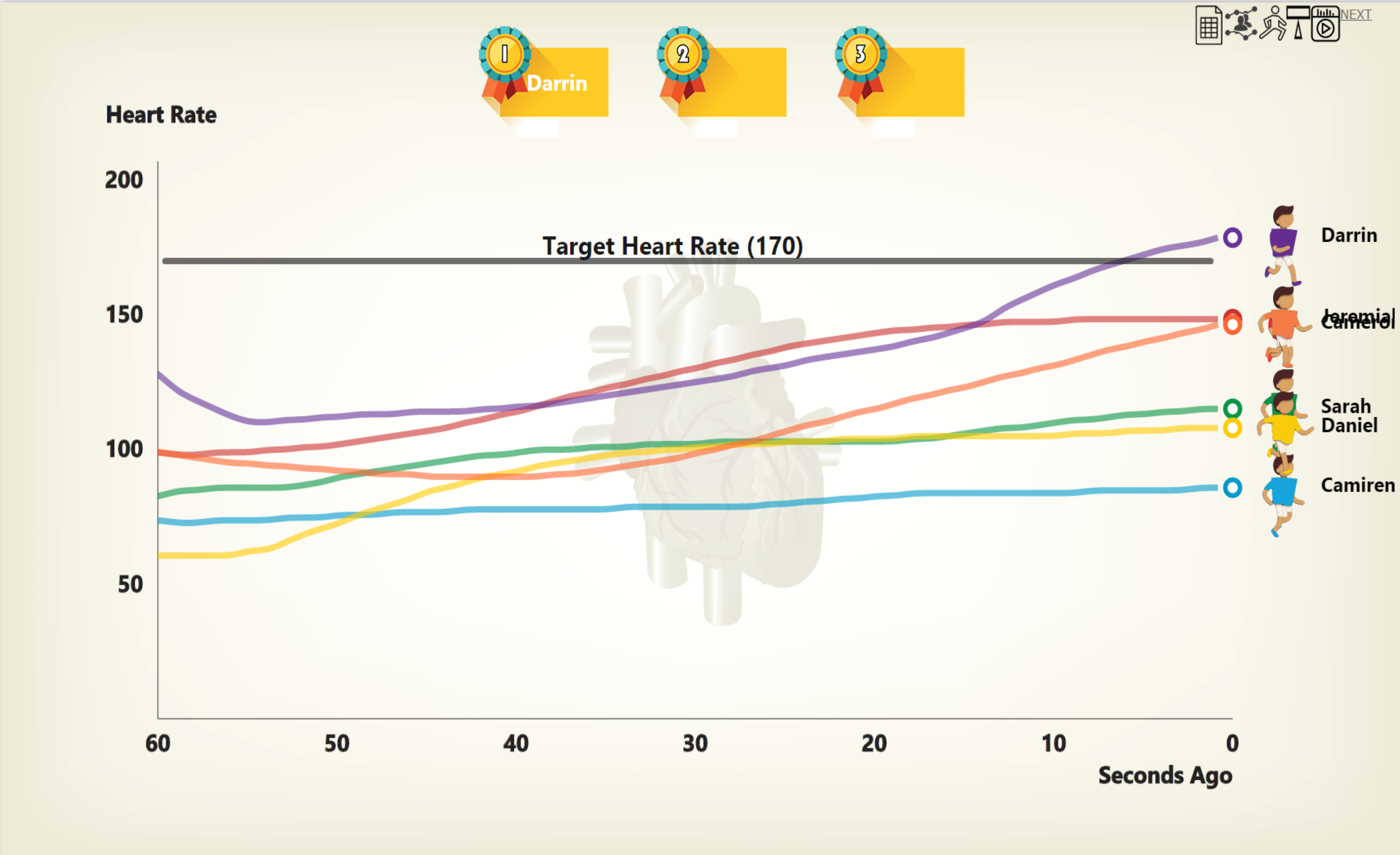

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LPSV + Personal Relevance

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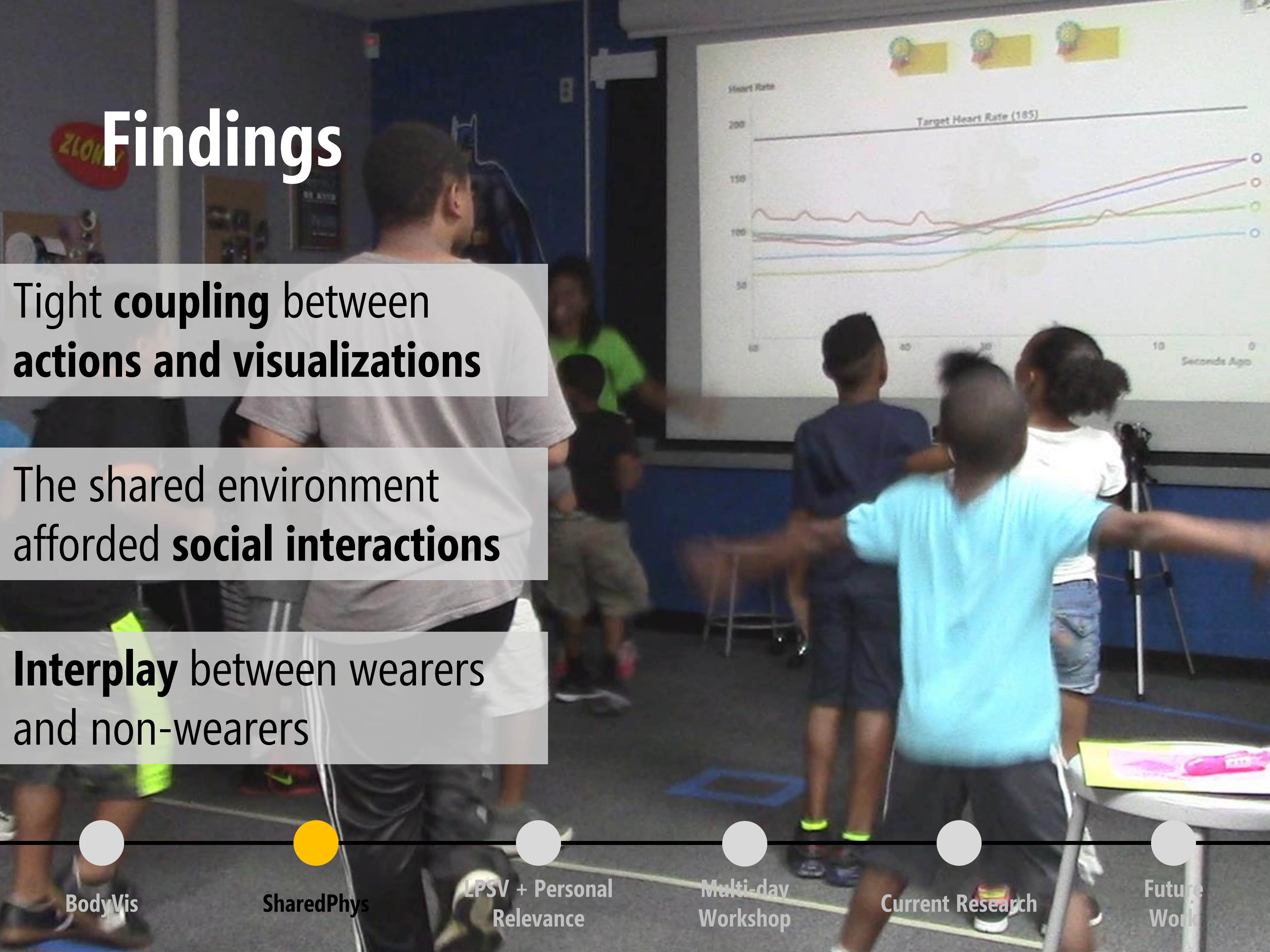
Moving Graphs

Findings

Tight **coupling** between **actions and visualizations**

The shared environment afforded **social interactions**

Interplay between wearers and non-wearers



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Building on the above work, this paper introduces and evaluates *SharedPhys*, which integrates live-streaming physiological sensors, whole-body interaction, and real-time large-screen visualizations to create a novel mixed-reality learning environment. With SharedPhys, children interact *physically*—both explicitly via body movement, gesture, and position as well as implicitly via their changing physiology. While prior work has explored body-centric inquiry (*e.g.*, [32, 36, 37]), the data collection and subsequent analyses are often disjoint and performed on a traditional computer setup. In contrast, our work simultaneously involves the body in data collection, interaction, and analysis creating new opportunities for feedback loops and playful experimentation. Similarly, while recent work has explored mixed-reality environments for collaborative learning, most have utilized simulations (*e.g.*, [12, 42, 47]) or artificial data (*e.g.*, [58]). Our work combines live streams of *real* body-data in a shared environment. We believe this tight coupling between physical action, physiological sensing, and live visualization offers new, rich possibilities for user interaction and learning experiences.

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LPSV Tools and Personal Relevance

"*That's your heart!*": Live Physiological Sensing & Visualization Tools for Life-Relevant & 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).

Live Physiological Sensing and Visualization (LPSV) Tools

BodyVis

SharedPhys

How should designers create **wearable technologies**, and the **experiences around them**, to help elementary-aged children **understand abstract concepts**?

1 **Design consideration s** for wearables

2 Help children make **life-relevant connections** with the information

3 Encourage children to **think in new ways**

How do **LPSV tools** support **life-relevant** STEM learning experiences for youth?

Learning Activities

How do **LPSV tools** support **life-relevant** STEM learning experiences for youth?

BodyVis · SharedPhys · **LPSV + Personal Relevance** · Multi-day Workshop · Current Research · Future Work

Learning Activities for LPSV Tools

Learning Activities for LPSV Tools

Participatory Design

Learning Activities for LPSV Tools

Participatory Design

Goal

To collaboratively design learning activities that utilized our LPSV tools

Learning Activities for LPSV Tools

Participatory Design

BodyVis | SharedPhys | **LPSV + Personal Relevance** | Multi-day Workshop | Current Research | Future Work

Learning Activities for LPSV Tools

Participatory Design

Learning Activities for LPSV Tools

Participatory Design

Learning Activities for LPSV Tools

Participatory Design

The Resulting Learning Activities

Small groups or pairs brainstorm activities

Make predictions

Test with BodyVis or SharedPhys

Discuss results

BodyVis · SharedPhys · **LPSV + Personal Relevance** · Multi-day Workshop · Current Research · Future Work

Sessions

BodyVis

SharedPhys

Sessions

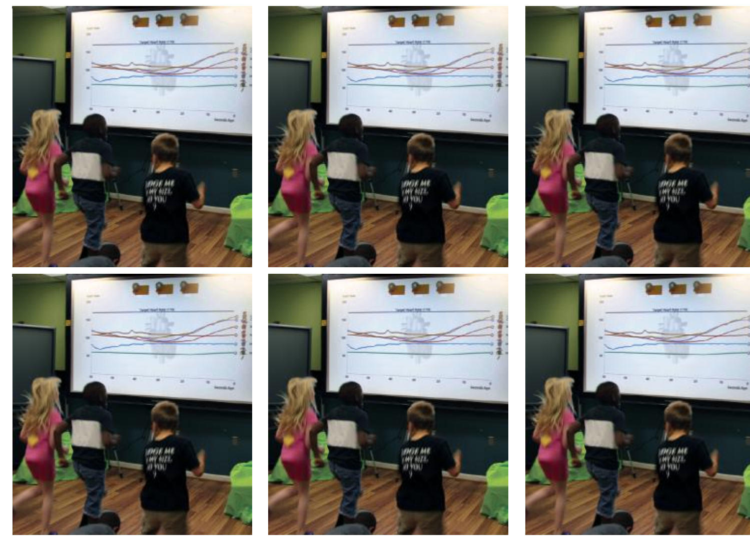
BodyVis

SharedPhys

Sessions

BodyVis

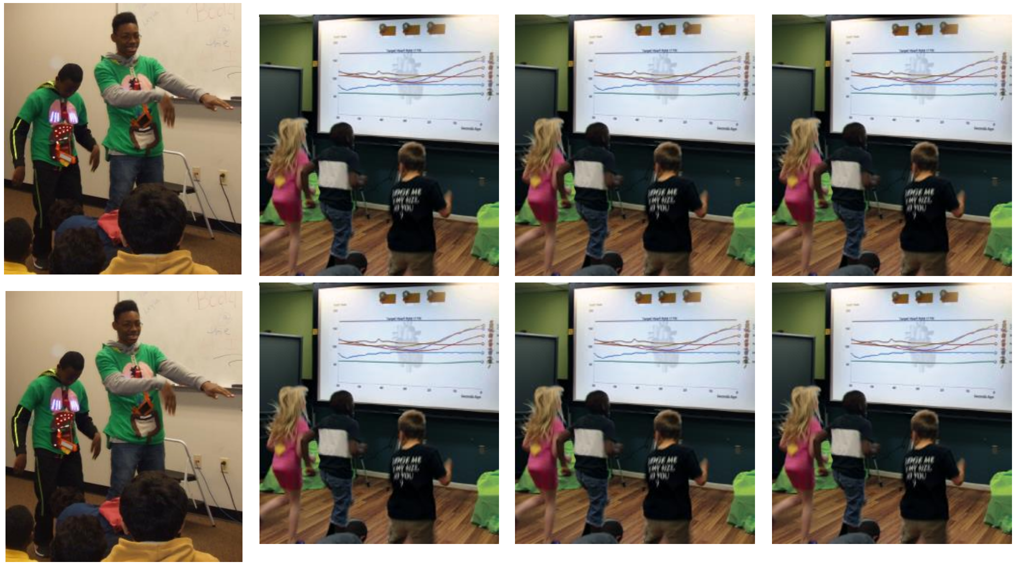
SharedPhys



Sessions

Joint 2nd and 3rd grade private school classroom

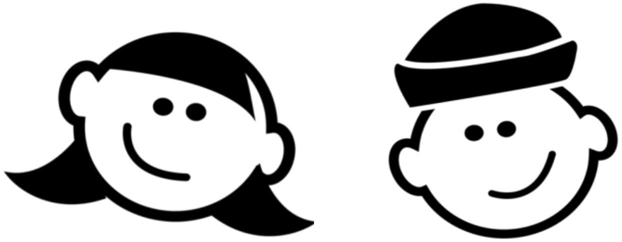
Out of school programs (Boys & Girls Club)



Participants (Total)

5-13
Ages

130
Participants



54 Female

76 Male

Analysis

Life-relevant Experiences

Indicators of linking experiences to everyday life, demonstrations of excitement and curiosity

Collaboration

Ways wearers and non-wearers interacted

Analysis

Life-relevant Experiences

Indicators of linking experiences to everyday life, demonstrations of excitement and curiosity

Collaboration

Ways wearers and non-wearers interacted

Findings: Life-Relevance

Both Tools

Children utilized everyday activities to form questions and hypotheses

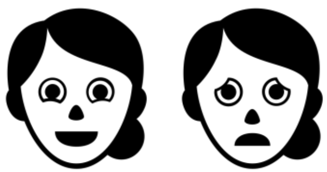
Findings: Life-Relevance

BodyVis

SharedPhys

Findings: Life-Relevance

BodyVis



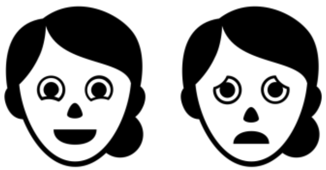
Emotion → Physiology

SharedPhys

> I kind of felt embarrassed because all these people were staring at me. So it kind of went up.

Findings: Life-Relevance

BodyVis



Emotion → Physiology

SharedPhys

Connection between bodies & visualization

BodyVis

SharedPhys

LPSV + Personal Relevance

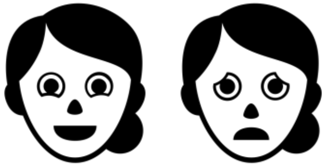
Multi-day Workshop

Current Research

Future Work

Findings: Life-Relevance

BodyVis



Emotion → Physiology

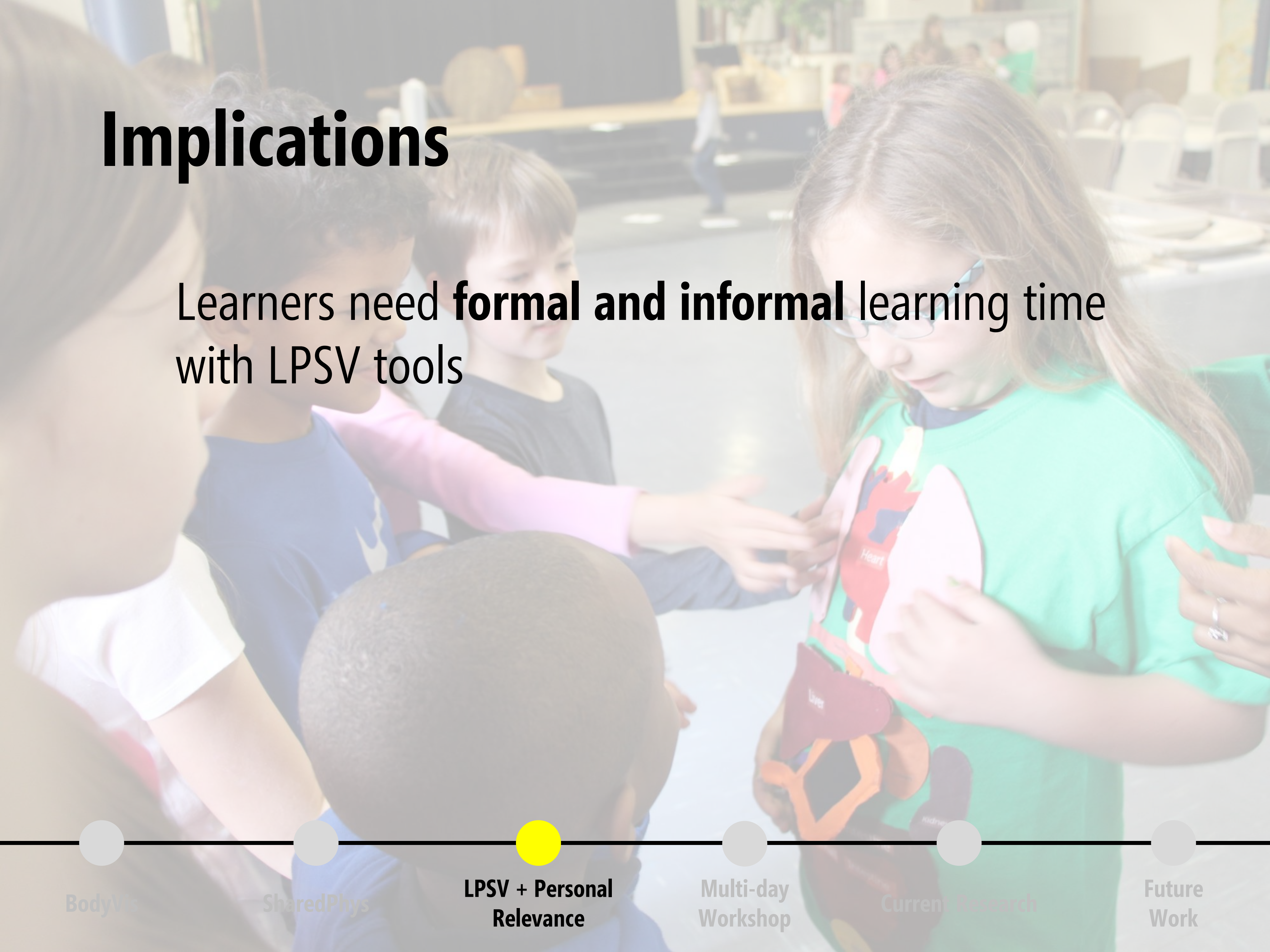
SharedPhys

Connection between bodies & visualization

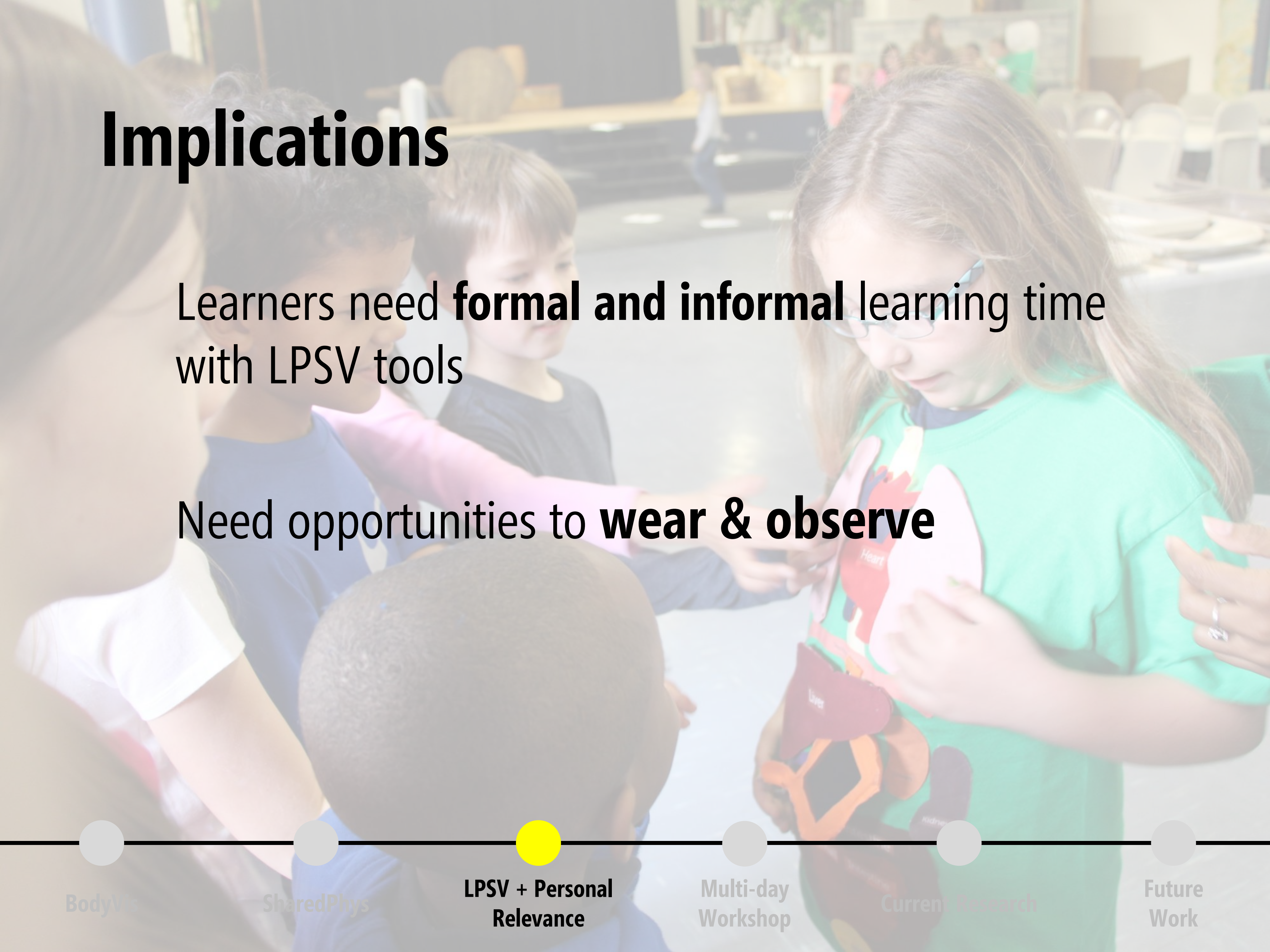
Games and competition

BodyVis | SharedPhys | **LPSV + Personal Relevance** | Multi-day Workshop | Current Research | Future Work

Implications



Learners need **formal and informal** learning time with LPSV tools



Implications

Learners need **formal and informal** learning time with LPSV tools

Need opportunities to **wear & observe**

BodyVis — SharedPhys — **LPSV + Personal Relevance** — Multi-day Workshop — Current Research — Future Work

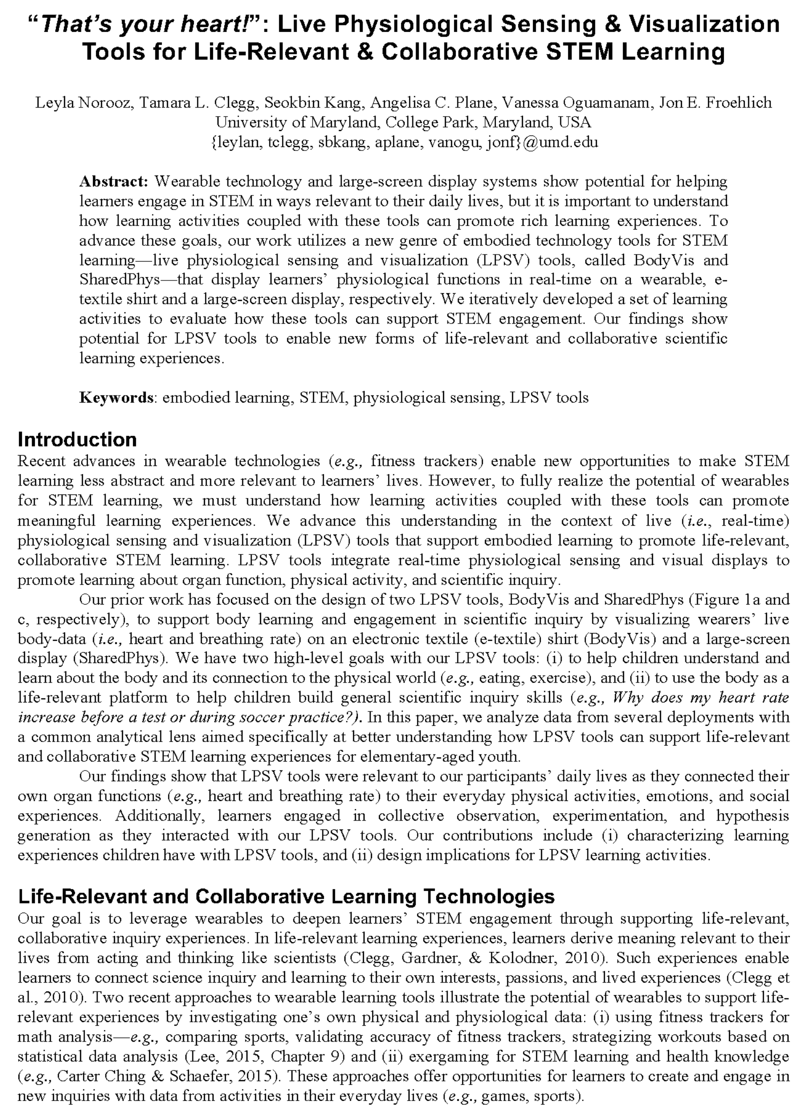
Implications

Learners need **formal and informal** learning time with LPSV tools

Need opportunities to **wear & observe**

Learning contexts should be **flexible**

LPSV Tools and Personal Relevance



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Multi-day Workshop

Live Physiological Sensing and Visualization Ecosystems: An Activity Theory Analysis

Tamara Clegg[1,2], Leyla Norooz[1], Seokbin Kang[3], Virginia Byrne[2], Monica Katzen[4], Rafael Velez[2], Angelisa Plane[3], Vanessa Oguamanam[1], Thomas Outing[3], Jason Yip[5], Elizabeth Bonsignore[1], Jon Froehlich[3]

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Figure 1. In this paper, we present a four-day deployment study of *LPSV* tools in a formal classroom environment where **(a)** children brainstorm questions, test hypotheses with a model-based tool called **(b)** *BodyVis* and with an analytic-based tool called **(c)** *SharedPhys*, and **(d)** present their experiment results.

ABSTRACT

Wearable sensing poses new opportunities to enhance personal connections to learning and authentic scientific inquiry experiences. In our work, we leverage the body and physical action as an engaging platform for learning through *live physiological sensing* and *visualization* (LPSV). Prior research suggests the potential of this approach, but was limited to single-session evaluations in informal environments. In this paper, we examine LPSV tools in a classroom environment during a four-day deployment. To highlight the complex interconnections between space, teachers, curriculum, and tool use, we analyze our data through the lens of *Activity Theory*. Our findings show the importance of integrating model-based representations for supporting exploration and analytic representations for scaffolding scientific inquiry. Activity Theory highlights leveraging life-relevant connections available within a physical *space* and considering policies and norms related to learners' physical *bodies*.

Author Keywords

Scientific inquiry, SBL, LPSV, wearables for learning

ACM Classification Keywords

H.5.m. Information interfaces and presentation (*e.g.*, HCI)

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INTRODUCTION

With the emergence of cheap and reliable wearable activity trackers, there has been renewed interest in the role of sensors for learning and education [4,26,27,29]. Indeed, wearable sensing capabilities pose new opportunities to significantly enhance personal connections to learning and authentic scientific inquiry experiences (*i.e.*, asking questions, collecting and analyzing data, making claims) [7]. For example, trackers that learners wear on their wrists or clothes can seamlessly collect data about one's physical activity (*e.g.*, steps taken) and vitals (*e.g.*, heart rate) throughout the day that can be analyzed later on mobile or desktop devices [4,28]. These new capabilities also significantly increase learners' opportunities to apply scientific inquiry to their daily life experiences—to *scientize* everyday life [8,9].

We are particularly interested in leveraging the body and physical action as a platform for learning through *live physiological sensing and visualization* (LPSV) [22,42]. LPSV tools sense and visualize learners' physiological functioning (*e.g.*, heart rate, breathing rate) in real-time, projecting analytic (*i.e.*, graph-based) and model-based representations of the data. For example, *BodyVis* [44] and *SharedPhys* [22] are two LPSV tools that visualize wearers' live body-data on an electronic textile (e-textile) shirt and a large-screen display respectively (Figure 1).

While research on applying wearable sensing to educational technology is still in its infancy, it builds on a long history of prior research on *sensor-based learning* (SBL) (e.g., [19,31,53,55]). These studies have shown the effectiveness of real-time analytic data (*e.g.*, real-time graphs of changes in one's motion) (e.g., [41,53]) and model-based representations [13,31] for supporting authentic scientific

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1 **Design consideration s** for wearables

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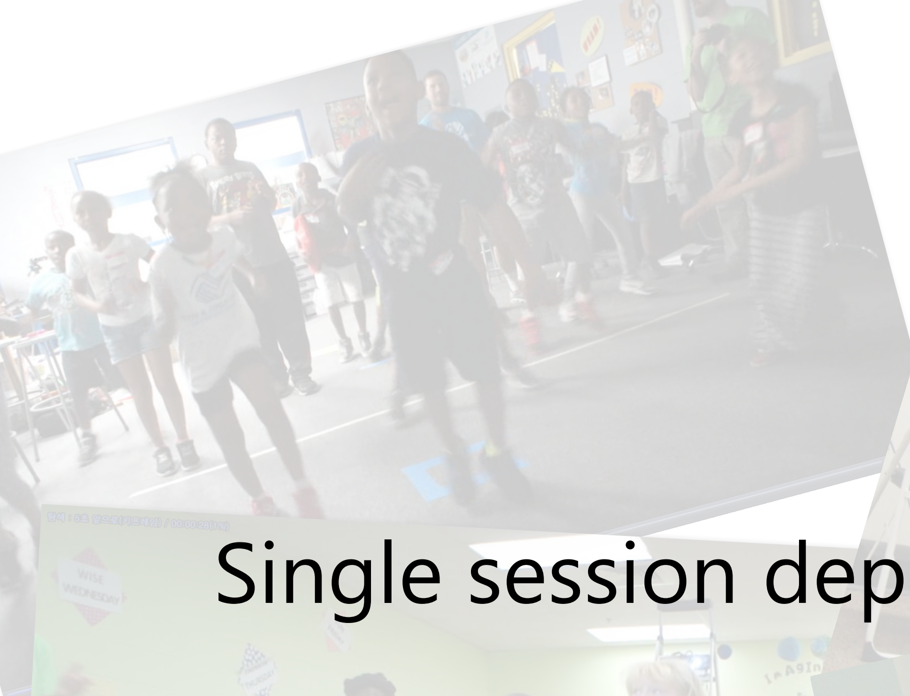
Single session deployments for each tool



Single session deployments for each tool

Limited amount of time for lots of activities


2002
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The use of microcomputer based laboratories in chemistry secondary education: Present state of the art and ideas for research-based practice

Montserrat Tortosa

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DOI: 10.1039/c2rp00019a

In microcomputer based laboratories (MBL) and data loggers, one or more sensors are connected to an interphase and this to a computer. This equipment allows visualization in real time of the variables of an experiment and provides the possibility of measuring magnitudes which are difficult to measure with traditional equipment. Research shows that the advantages of using this technology go further than simply motivating students as they can improve other abilities, such as interpretation of graphs, and it can help to develop several competencies and higher order learning skills in students. The aims of this study are to learn about the potential of MBL in chemistry classrooms and to present a framework for research based lab sheets. In this work, research reporting significant learning in secondary school chemistry laboratory using an inquiry approach related to microcomputer based laboratory experiences is reviewed. Instructional effectiveness of the technology, research based materials for students, ideas for practice and opinions of teachers and students when using this technology are reviewed.

Introduction

Significant learning in the chemistry laboratory

The idea that meaningful learning is possible in the laboratory if students are given opportunities to manipulate equipment and materials in a suitable environment (Tobin, 1990) is widely accepted, but research in didactics has not found simple relationships between laboratory experiences and the learning outcomes of students (Hofstein and Lunetta, 1982, 2003). The science laboratory is a unique learning environment as it has the potential to provide science teachers with opportunities to vary their instructional techniques and to avoid a monotonous classroom learning environment. Although it has been demonstrated that traditional teaching methods do not solve students' learning difficulties, even for those who wish to become scientists, there are various opinions on how to teach or how to apply the results of the research on science education into school laboratories. It is generally accepted that meaningful learning takes place when students not only remember but also make sense of and are able to apply what they have learned (Anderson and Krathwohl, 2001), and that there is a considerable amount of evidence collected by researchers of science teaching that traditional instructional methods, largely lectures and undertaking exercises, are not effective methods for all learners. Sufficient data do exist to suggest that laboratory instruction is an effective and efficient teaching medium to attain some of the goals for teaching and learning science and that appropriate laboratory activities have a great potential in promoting positive attitudes and in providing students with opportunities to develop skills regarding cooperation and communication (Hofstein, 2003; Hofstein and Mamlok-Naaman, 2007).

To improve science competencies in citizenship, inquiry-based science education (IBSE) has been proposed by many science researchers and educators. IBSE has proven its efficacy at both primary and secondary level increasing students' interest and attainment level while motivating the teacher at the same time (Hofstein *et al.*, 2005; Fortus *et al.*, 2006; Rocard *et al.*, 2007; Barnea *et al.*, 2010). There is agreement (Rocard *et al.*, 2007) that inquiry is a good way of presenting laboratory work, and that to improve scientific literacy (PISA OECD, 2003) learners must have opportunities to practice selected skills. The analysis regarding the students' perceptions clearly demonstrates (Hofstein, 2003) that students who were involved in inquiry-type investigations found the laboratory learning environment to be more open-ended and more integrated with a conceptual framework than those students in a control group. They also found that the gap between the actual and the preferred learning environment on various levels was significantly smaller in the inquiry group than in the control group. Students perceived that they were more involved in the learning process and found the procedures more open-ended. The integration of laboratory experience with other pedagogical interventions and classroom instructional techniques was associated with a significant reduction in ... agnitude of the differences

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Of the studies that have taken place in formal classrooms...

Often **focus on a narrow set of components** in the ecosystem (e.g., teacher preparation, tool maintenance and management, curriculum)

How does the **LPSV ecosystem** influence children's **life-relevant connections** to **scientific inquiry**?

How does the **LPSV ecosystem** influence children's **life-relevant connections** to **scientific inquiry**?

Asking questions, collecting and analyzing data, making claims

BodyVis | SharedPhys | LPSV + Personal Relevance | **Multi-day Workshop** | Current Research | Future Work

Designing the Workshop

Previous Study → Implementation

Designing the Workshop

Previous Study →	Implementation
Learners need **formal and informal** learning time with LPSV tools	**Play** time and **mediated learning** time

Designing the Workshop

Previous Study →	Implementation
Learners need **formal and informal** learning time with LPSV tools	**Play** time and **mediated learning** time
Need opportunities to **wear & observe**	A **different children wears** a tool each day

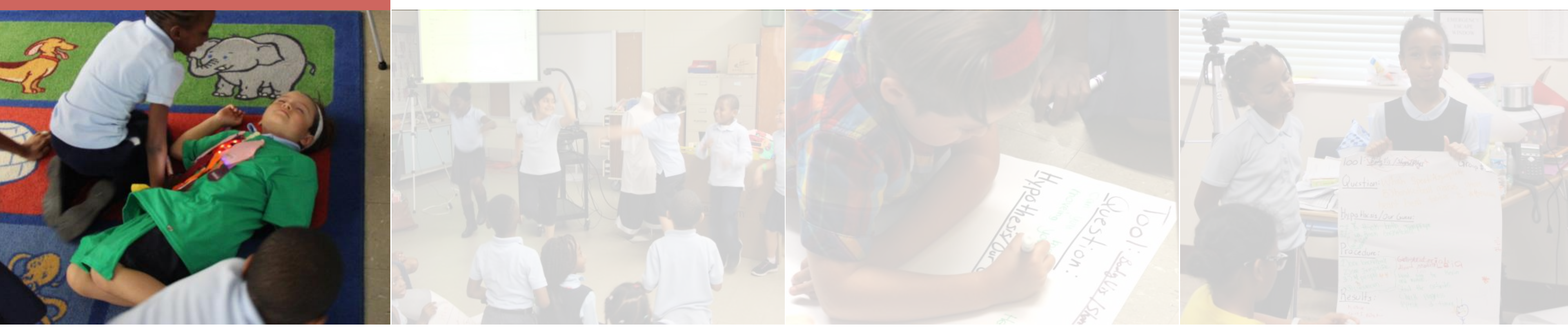
Designing the Workshop

Previous Study →	Implementation
Learners need **formal and informal** learning time with LPSV tools	**Play** time and **mediated learning** time
Need opportunities to **wear & observe**	A **different children wears** a tool each day
Learning contexts should be **flexible**	Children design **science experiments**

Day 1: Play and Discovery

Children **discussed questions** and engaged in **free-form exploration** with the tools in a scavenger hunt.

1. PLAY



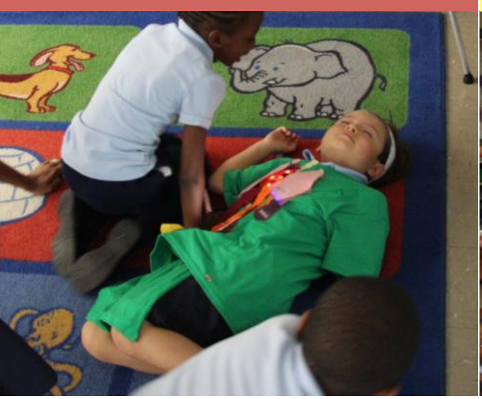
BodyVis · SharedPhys · LPSV + Personal Relevance · **Multi-day Workshop** · Current Research · Future Work

Day 2: Exploring Physical Activities

Children **brainstormed physical activities** with BodyVis.
They then **tested their hypotheses** with SharedPhys.

1. PLAY

2. EXPLORE

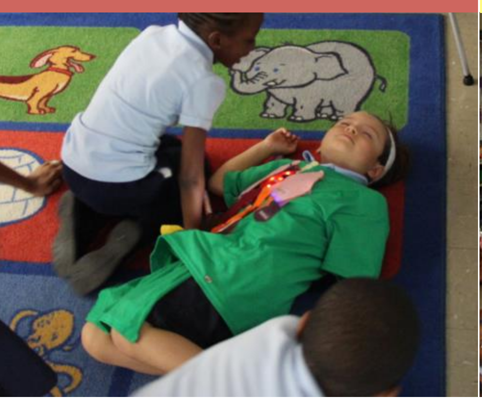


BodyVis
SharedPhys
LPSV + Personal Relevance
Multi-day Workshop
Current Research
Future Work

Day 3: Science Experiments

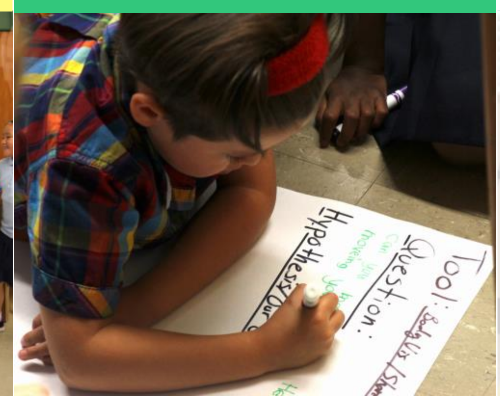
Children **planned scientific investigations** of their choosing with **BodyVis or SharedPhys**.

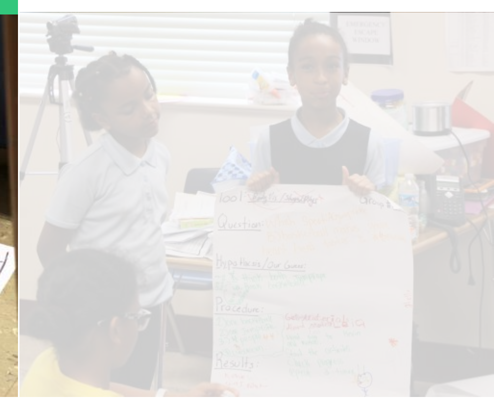
1. PLAY



2. EXPLORE

3. EXPERIMENT





BodyVis
SharedPhys
LPSV + Personal Relevance
Multi-day Workshop
Current Research
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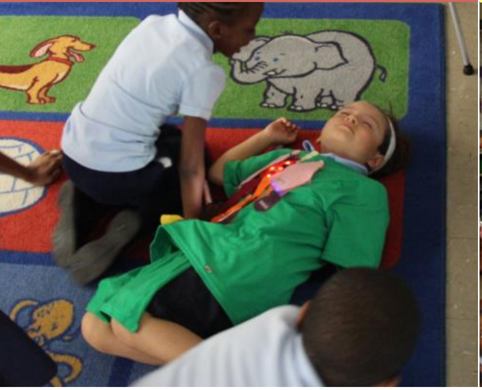
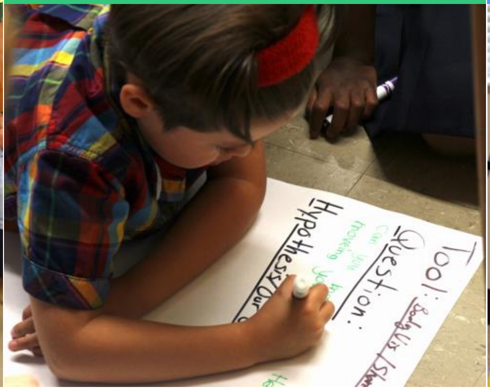
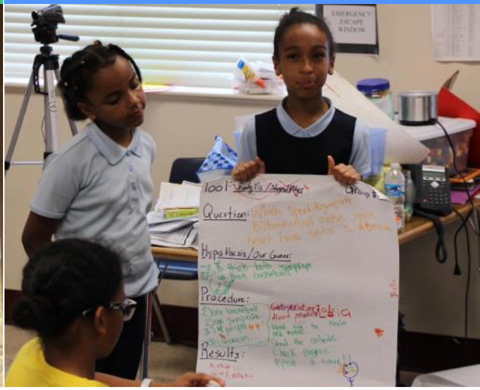
Day 4: Presentations

Children **presented** their choice-based investigations.

1. PLAY	2. EXPLORE	3. EXPERIMENT	4. PRESENT

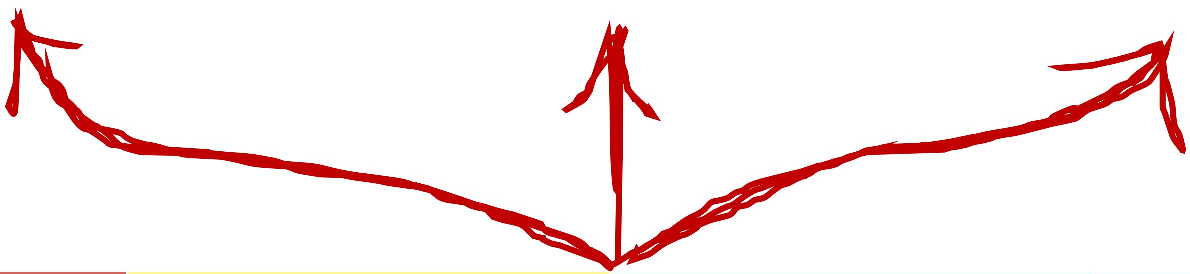




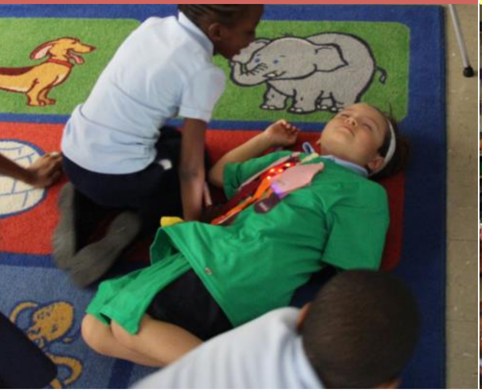


4-Day Workshops

1st Grade | 2nd Grade | 4th Grade

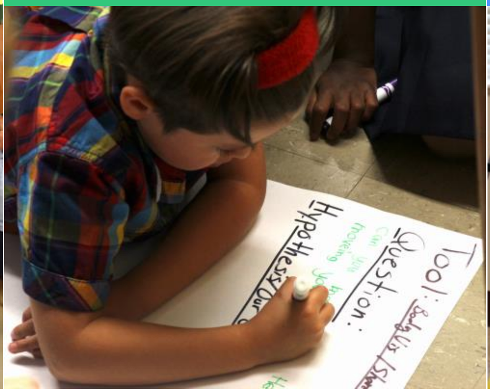


1. PLAY

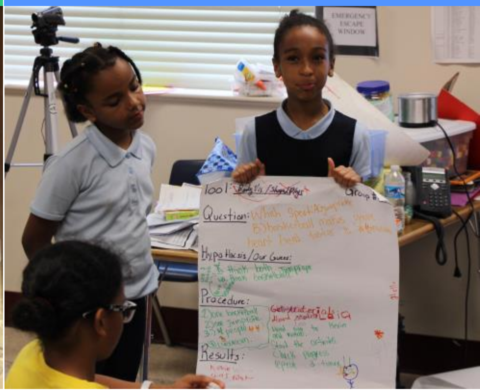


2. EXPLORE

3. EXPERIMENT



4. PRESENT



BodyVis — SharedPhys — LPSV + Personal Relevance — **Multi-day Workshop** — Current Research — Future Work

4-Day Workshops

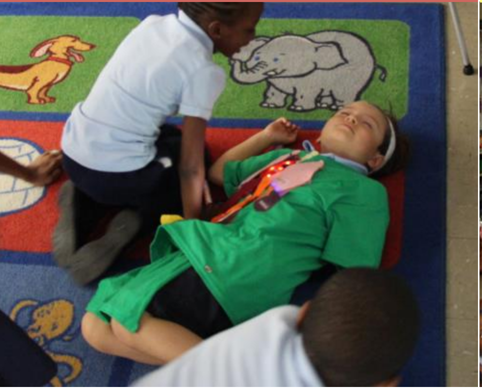
1st Grade

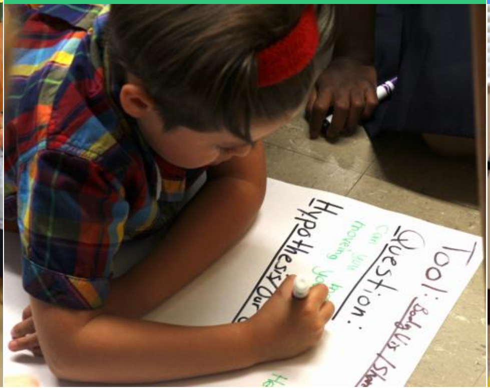
2nd Grade

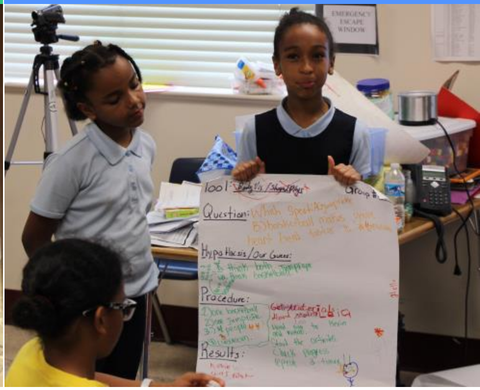
4th Grade

12 Days Total

1. PLAY	2. EXPLORE	3. EXPERIMENT	4. PRESENT







Participants (Total)

65
Participants

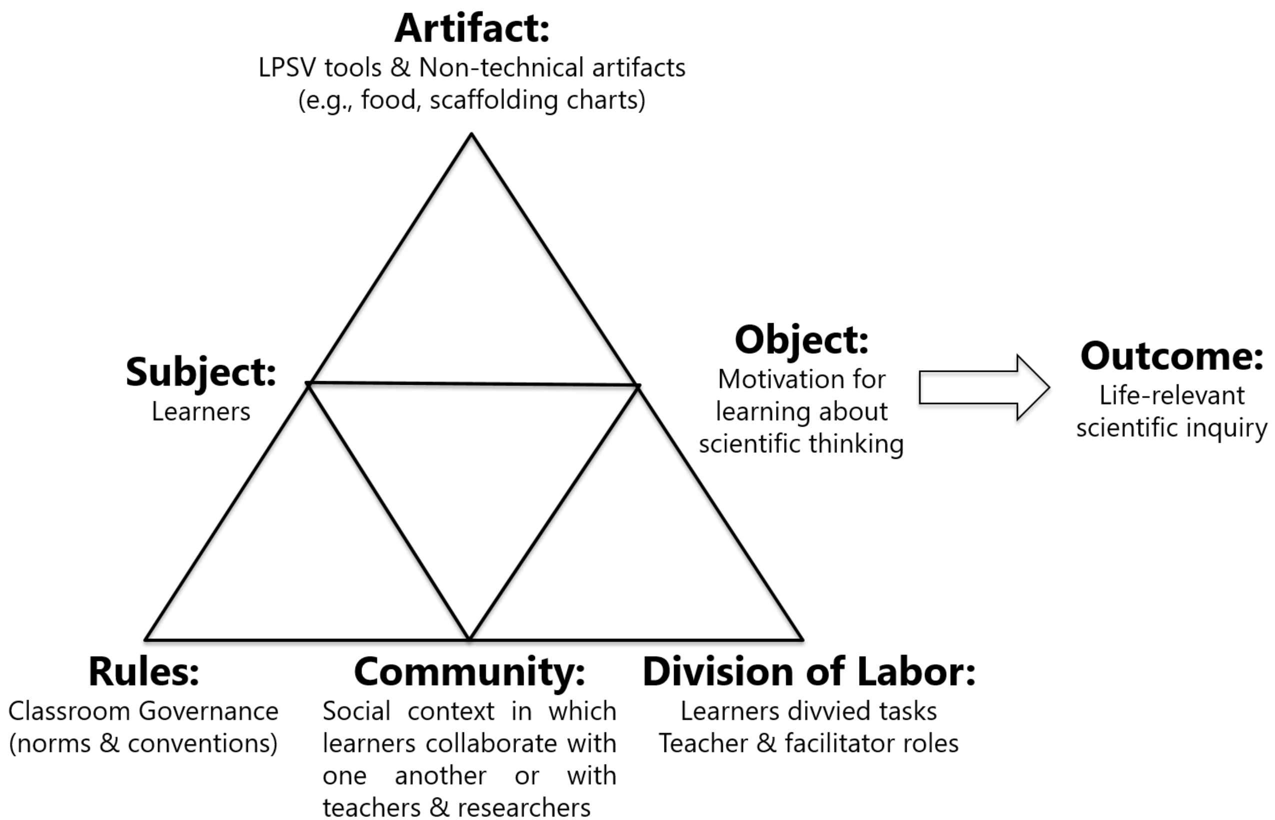
27 Female

24 Male

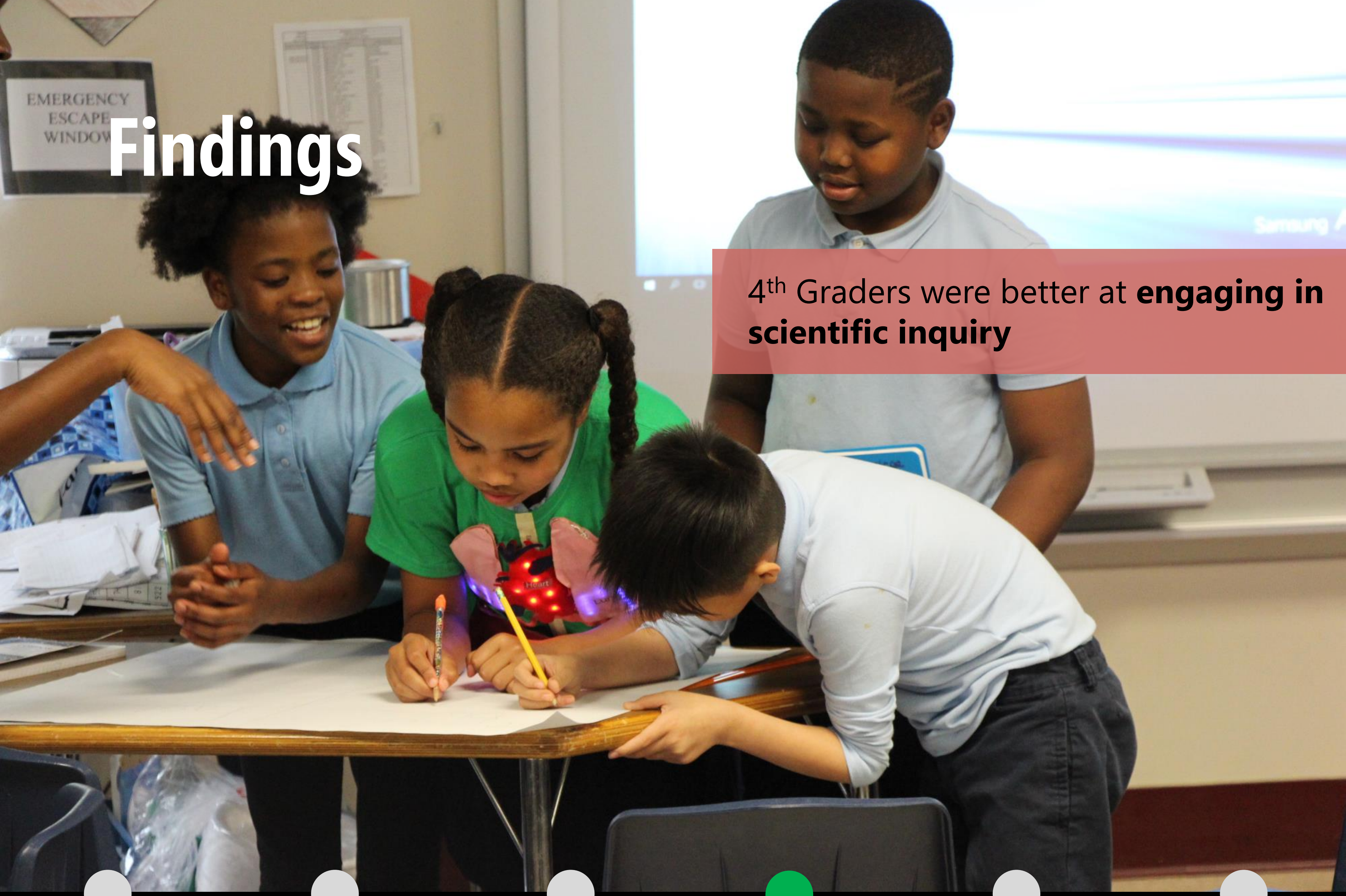
Undisclosed 11

Activity Theory Analysis

Activity Theory places an emphasis on analyzing the interaction between **people**, **artifacts**, and **social groups**.



Findings



4th Graders were better at **engaging in scientific inquiry**

Findings

4th Graders were better at **engaging in scientific inquiry**

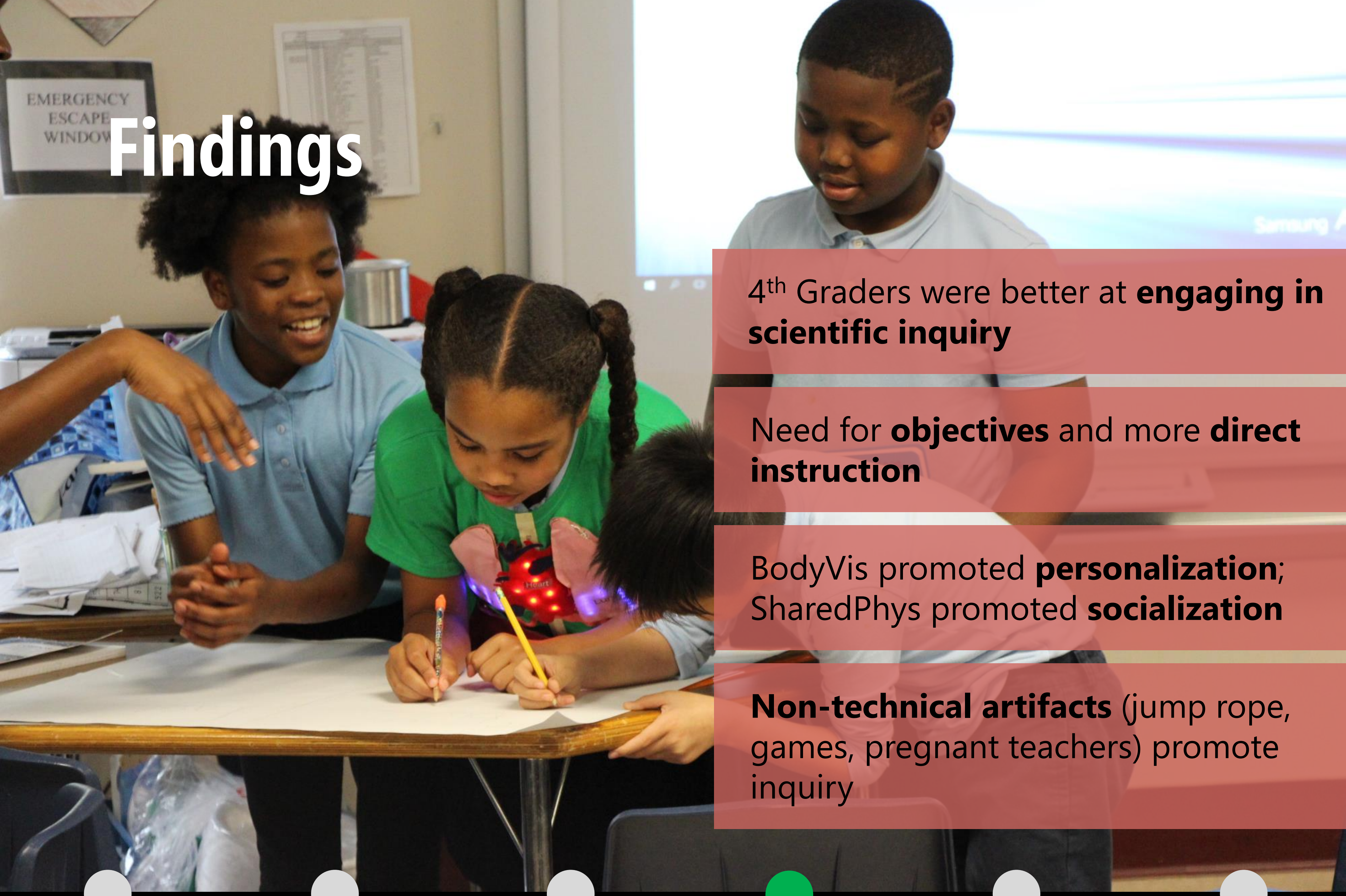
Need for **objectives** and more **direct instruction**

Findings

4th Graders were better at **engaging in scientific inquiry**

Need for **objectives** and more **direct instruction**

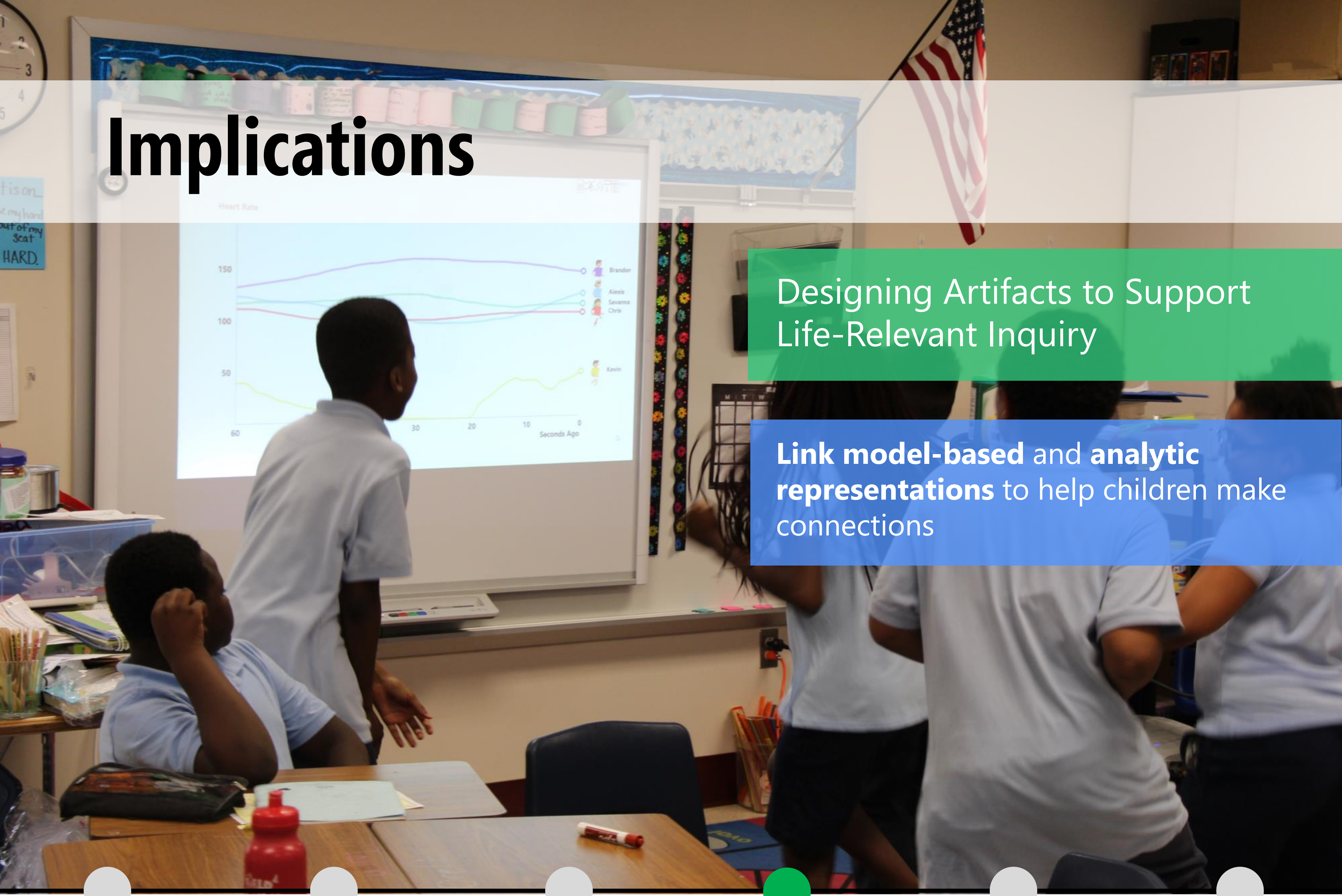
BodyVis promoted **personalization**; SharedPhys promoted **socialization**



Findings

- 4th Graders were better at **engaging in scientific inquiry**
- Need for **objectives** and more **direct instruction**
- BodyVis promoted **personalization**; SharedPhys promoted **socialization**
- **Non-technical artifacts** (jump rope, games, pregnant teachers) promote inquiry

Implications

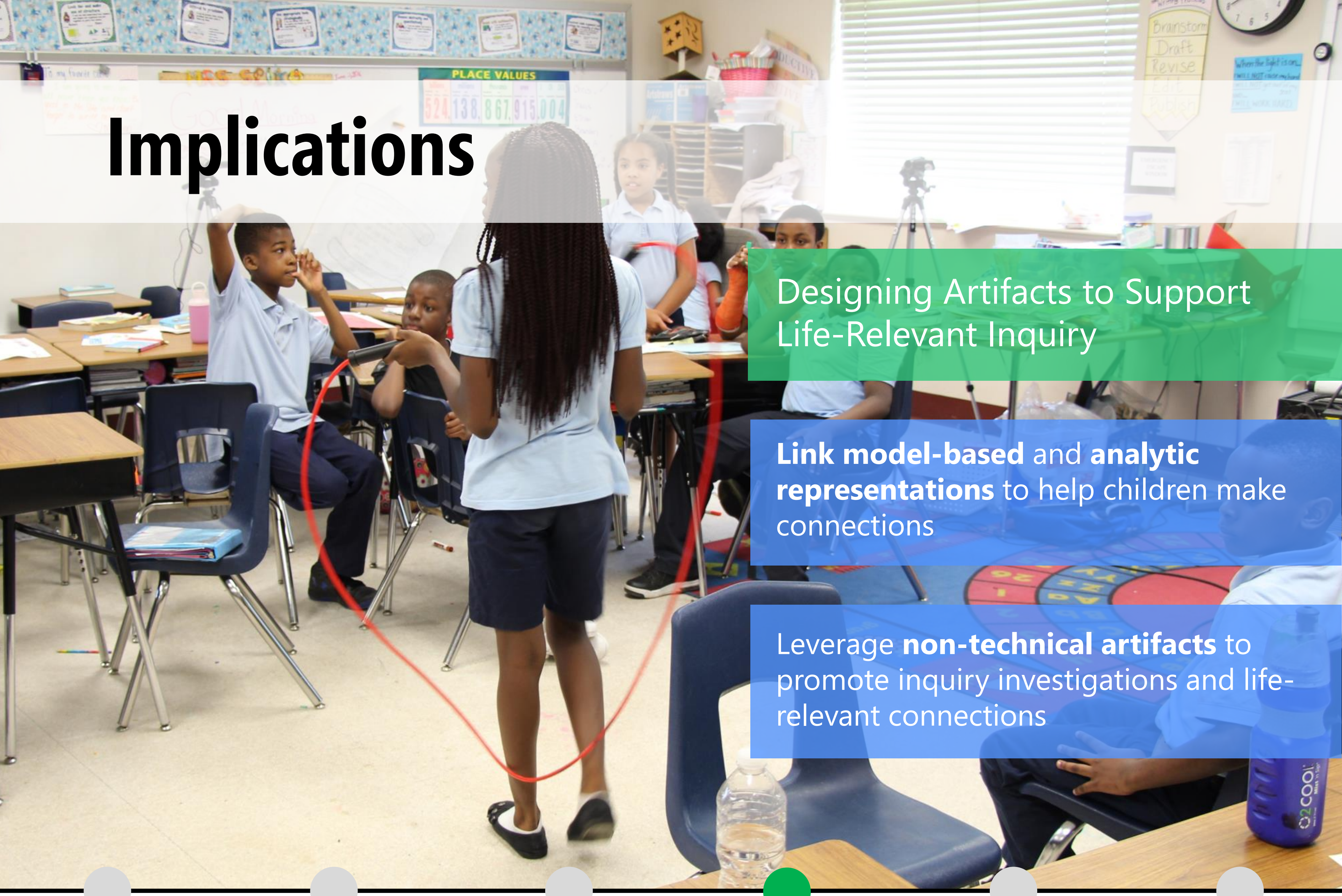


Designing Artifacts to Support Life-Relevant Inquiry

Link model-based and **analytic representations** to help children make connections

BodyVis | SharedPhys | LPSV + Personal Relevance | **Multi-day Workshop** | Current Research | Future Work

Implications



Designing Artifacts to Support Life-Relevant Inquiry

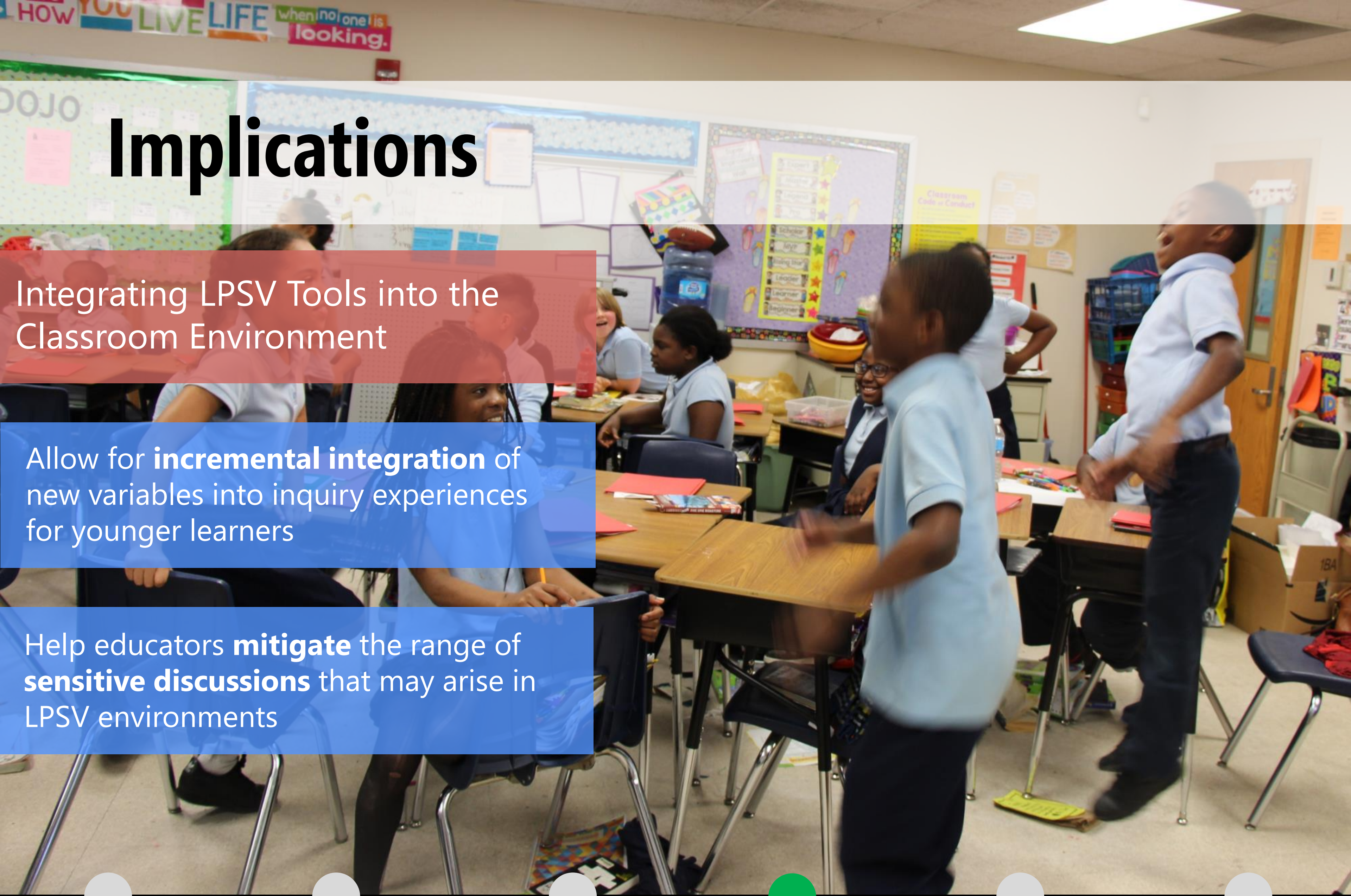
Link model-based and **analytic representations** to help children make connections

Leverage **non-technical artifacts** to promote inquiry investigations and life-relevant connections

Implications

Integrating LPSV Tools into the Classroom Environment

Allow for **incremental integration** of new variables into inquiry experiences for younger learners



Implications

Integrating LPSV Tools into the Classroom Environment

Allow for **incremental integration** of new variables into inquiry experiences for younger learners

Help educators **mitigate** the range of **sensitive discussions** that may arise in LPSV environments

Multi-day Workshop

Live Physiological Sensing and Visualization Ecosystems: An Activity Theory Analysis

Tamara Clegg[1,2], Leyla Norooz[1], Seokbin Kang[3], Virginia Byrne[2], Monica Katzen[4], Rafael Velez[2], Angelisa Plane[3], Vanessa Oguamanam[1], Thomas Outing[3], Jason Yip[5], Elizabeth Bonsignore[1], Jon Froehlich[3]

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Figure 1. In this paper, we present a four-day deployment study of *LPSV* tools in a formal classroom environment where **(a)** children brainstorm questions, test hypotheses with a model-based tool called **(b)** *BodyVis* and with an analytic-based tool called **(c)** *SharedPhys*, and **(d)** present their experiment results.

ABSTRACT

Wearable sensing poses new opportunities to enhance personal connections to learning and authentic scientific inquiry experiences. In our work, we leverage the body and physical action as an engaging platform for learning through *live physiological sensing* and *visualization* (LPSV). Prior research suggests the potential of this approach, but was limited to single-session evaluations in informal environments. In this paper, we examine LPSV tools in a classroom environment during a four-day deployment. To highlight the complex interconnections between space, teachers, curriculum, and tool use, we analyze our data through the lens of *Activity Theory*. Our findings show the importance of integrating model-based representations for supporting exploration and analytic representations for scaffolding scientific inquiry. Activity Theory highlights leveraging life-relevant connections available within a physical *space* and considering policies and norms related to learners' physical *bodies*.

Author Keywords

Scientific inquiry, SBL, LPSV, wearables for learning

ACM Classification Keywords

H.5.m. Information interfaces and presentation (*e.g.*, HCI)

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DOI: http://dx.doi.org/10.1145/3025453.3025987

INTRODUCTION

With the emergence of cheap and reliable wearable activity trackers, there has been renewed interest in the role of sensors for learning and education [4,26,27,29]. Indeed, wearable sensing capabilities pose new opportunities to significantly enhance personal connections to learning and authentic scientific inquiry experiences (*i.e.*, asking questions, collecting and analyzing data, making claims) [7]. For example, trackers that learners wear on their wrists or clothes can seamlessly collect data about one's physical activity (*e.g.*, steps taken) and vitals (*e.g.*, heart rate) throughout the day that can be analyzed later on mobile or desktop devices [4,28]. These new capabilities also significantly increase learners' opportunities to apply scientific inquiry to their daily life experiences—to *scientize* everyday life [8,9].

We are particularly interested in leveraging the body and physical action as a platform for learning through *live physiological sensing and visualization* (LPSV) [22,42]. LPSV tools sense and visualize learners' physiological functioning (*e.g.*, heart rate, breathing rate) in real-time, projecting analytic (*i.e.*, graph-based) and model-based representations of the data. For example, *BodyVis* [44] and *SharedPhys* [22] are two LPSV tools that visualize wearers' live body-data on an electronic textile (e-textile) shirt and a large-screen display respectively (Figure 1).

While research on applying wearable sensing to educational technology is still in its infancy, it builds on a long history of prior research on *sensor-based learning* (SBL) (e.g., [19,31,53,55]). These studies have shown the effectiveness of real-time analytic data (*e.g.*, real-time graphs of changes in one's motion) (e.g., [41,53]) and model-based representations [13,31] for supporting authentic scientific

Current Research

Iterating on the Workshop

Participatory Design with Teachers

Iterating on the Workshop

Participatory Design with Teachers

Goal

Cognitively **scale activities** and assessments with respect to grade level

Develop additional **scaffolding** materials to guide learning

Identify **key points for teachers** to address sensitive topics and control physical activity

Changes Made to the Workshop

Daily Objectives

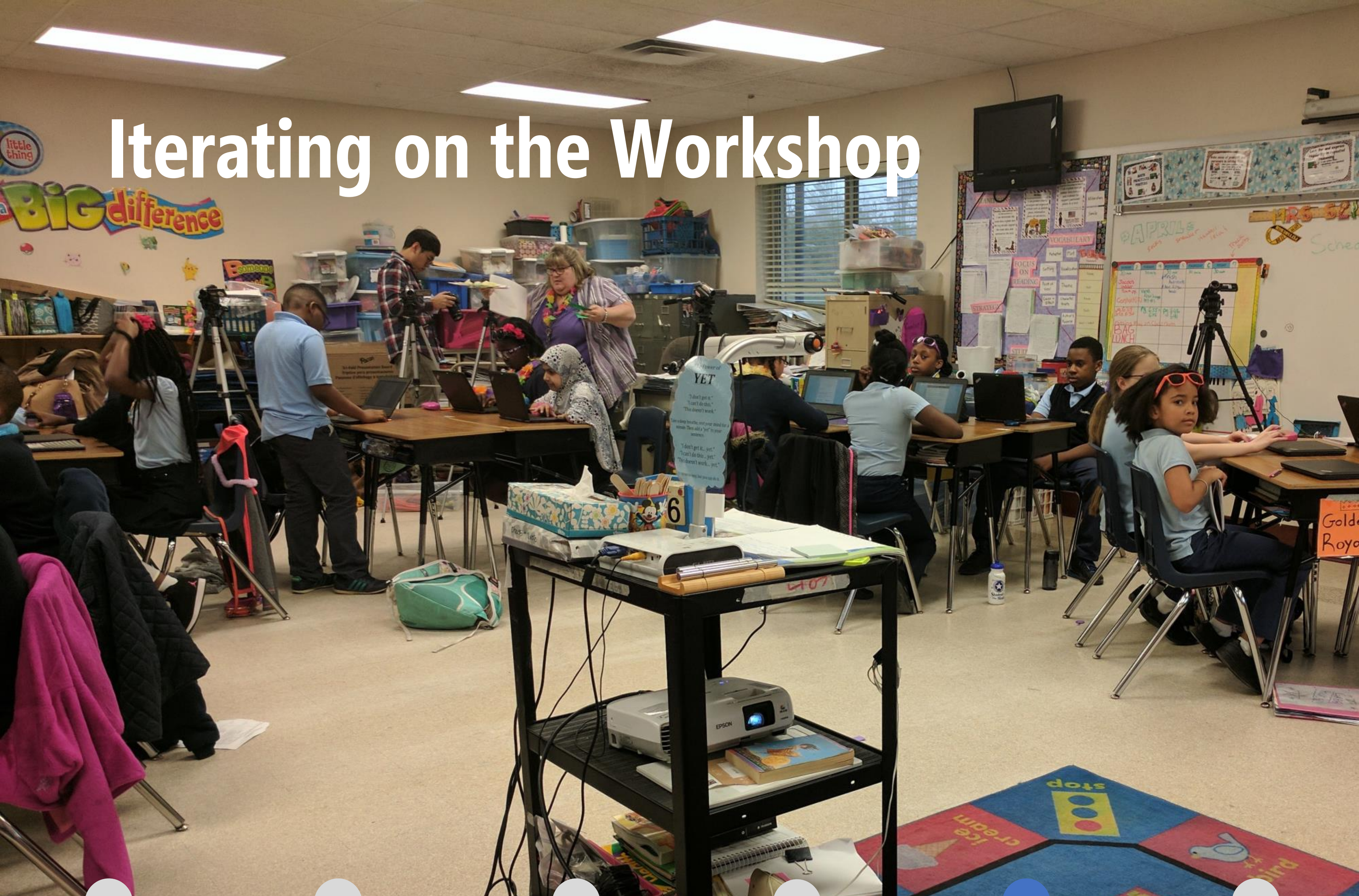
Changes Made to the Workshop

- Daily Objectives
- Structured Activities

Changes Made to the Workshop

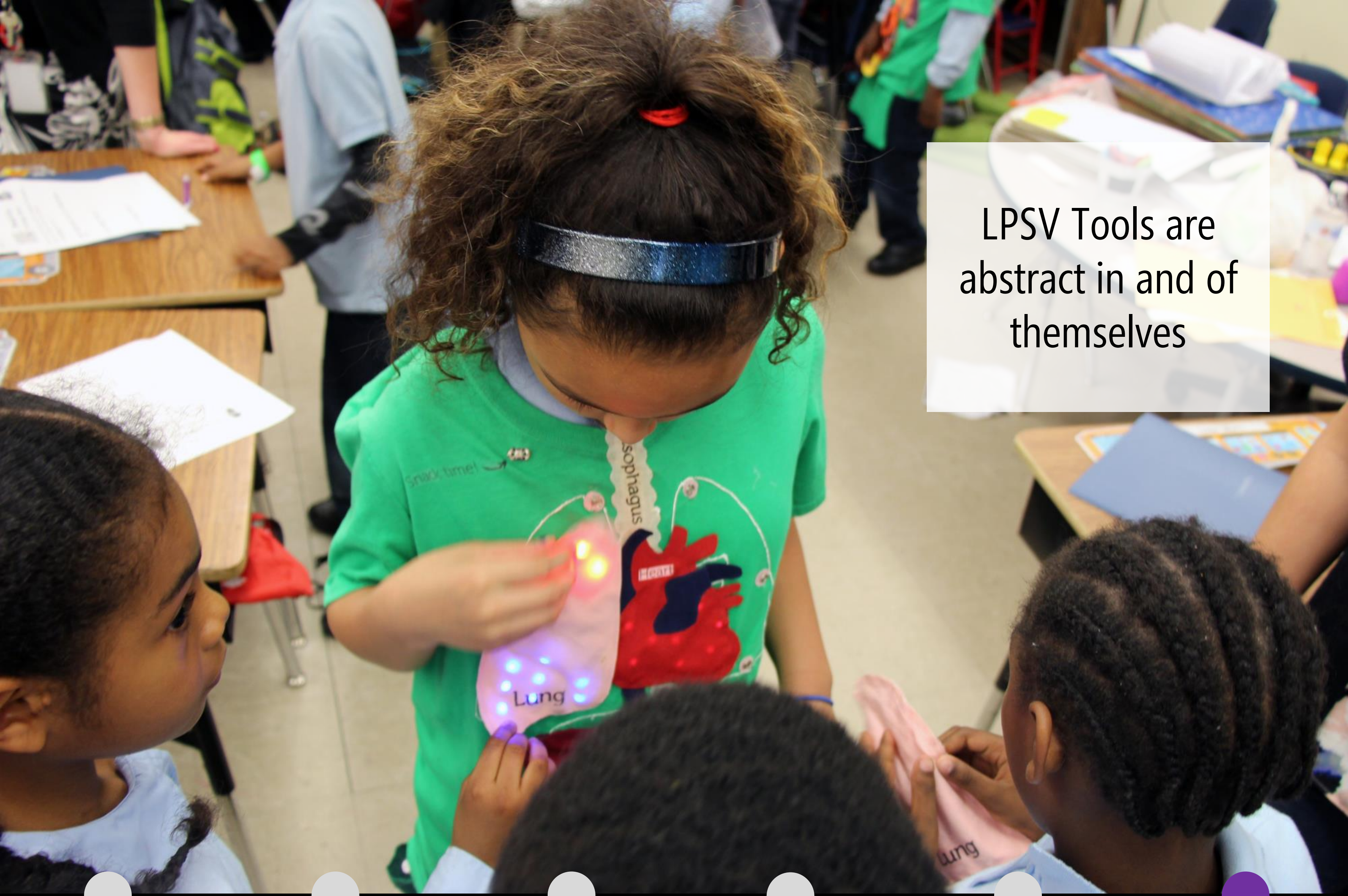
- Daily Objectives
- Structured Activities
- Cognitively Scaled Activities and Assessments

Iterating on the Workshop



Current Research

Future Work



LPSV Tools are abstract in and of themselves

How should designers create **wearable technologies**, and the **experiences around them**, to help elementary-aged children **understand abstract concepts**?

1 **Design considerations** for wearables

2 Help children make **life-relevant connections** with the information

3 Encourage children to **think in new ways**

BodyVis

SharedPhys

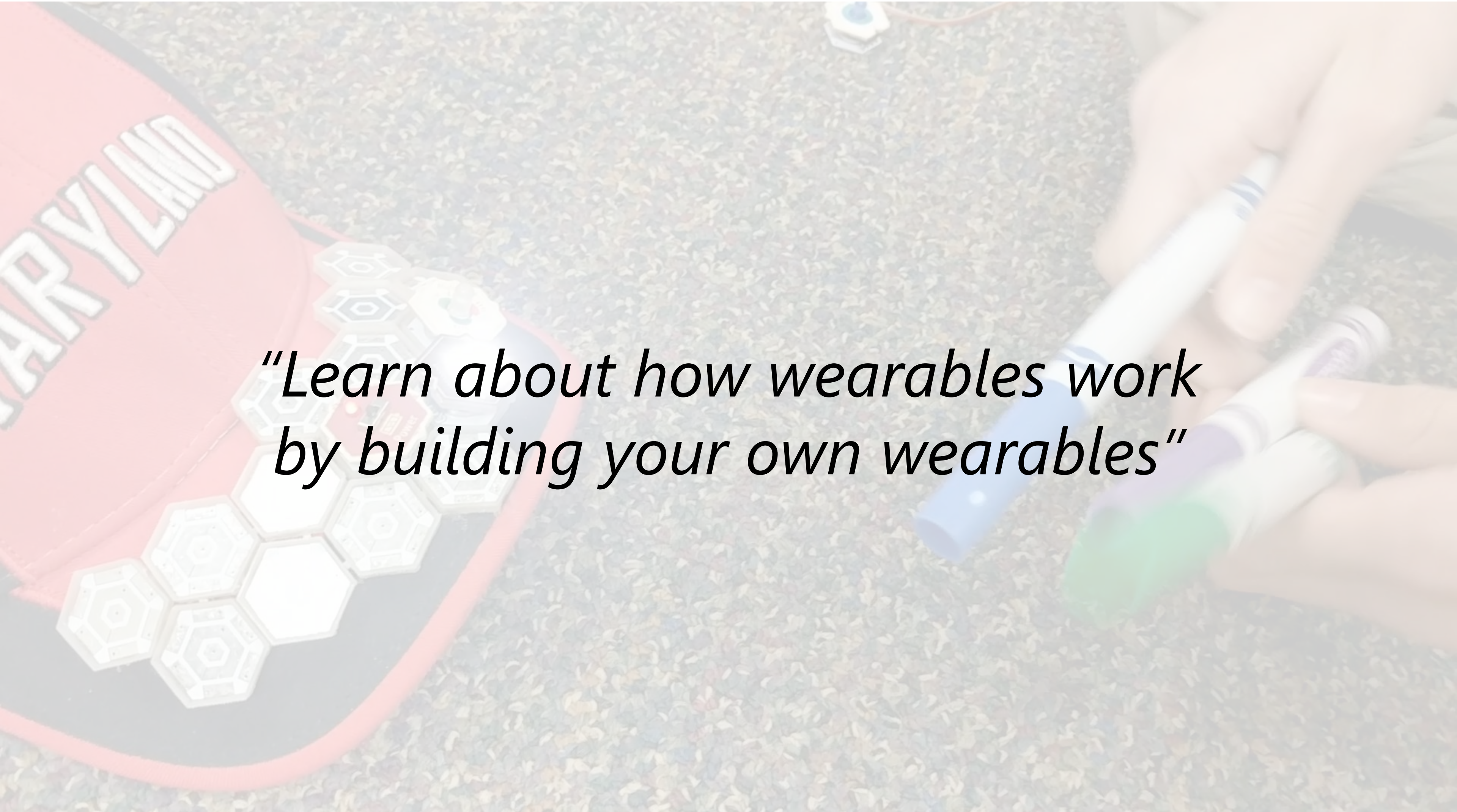
LPSV + Personal Relevance

Multi-day Workshop

Current Research

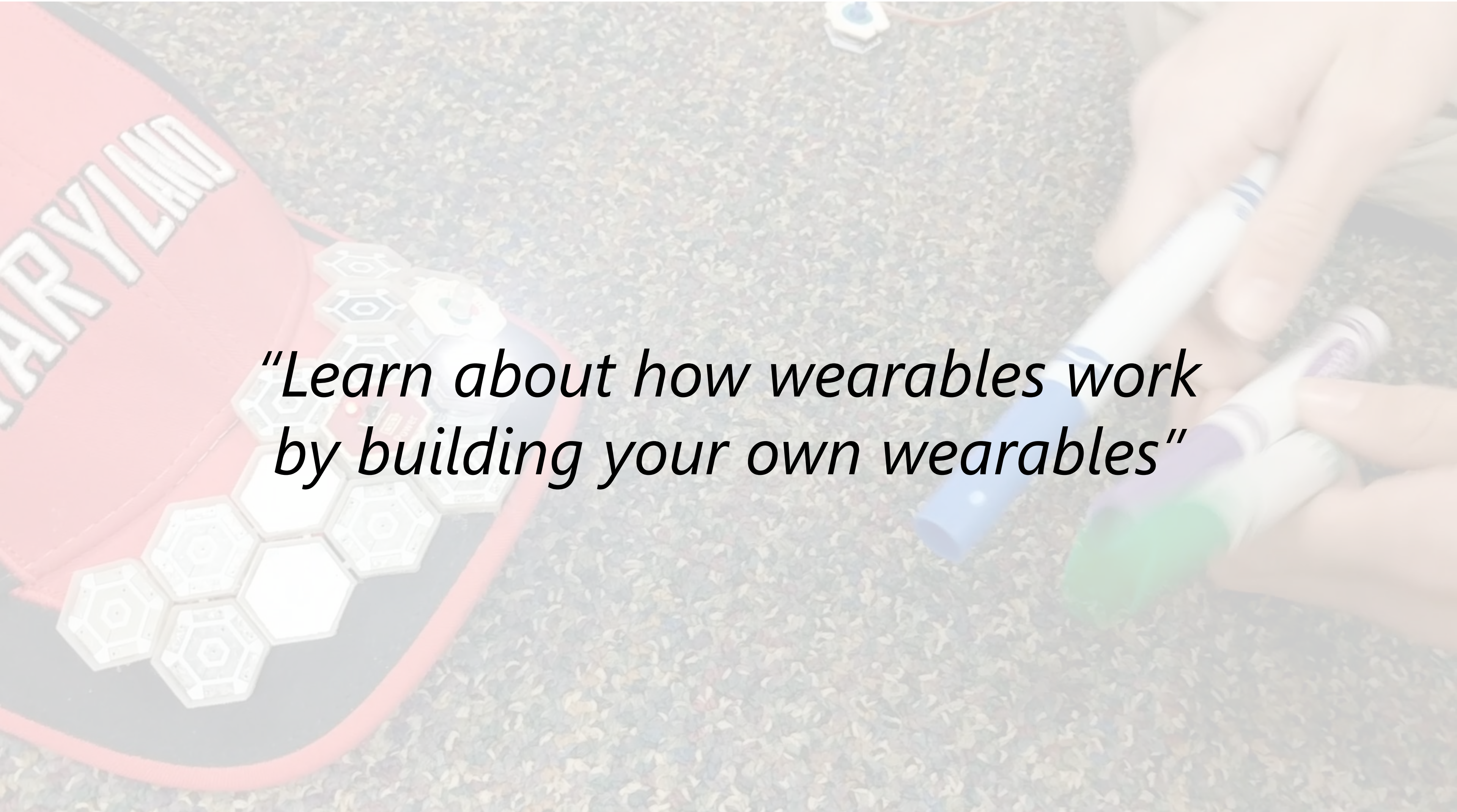
Future Work

Modeling Body Systems via Wearable Construction Kits



“Learn about how wearables work by building your own wearables”

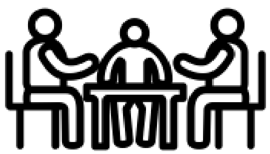
Modeling Body Systems via Wearable Construction Kits



“Learn about how wearables work by building your own wearables”

Key Takeaways

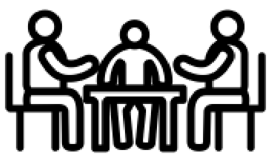
When designing wearable technologies for school environments:



Involve *all* stakeholders in every step of the design process

Key Takeaways

When designing wearable technologies for school environments:

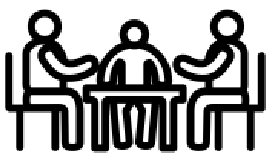


Involve *all* stakeholders in every step of the design process

Consider pre-established dynamics of the environment

Key Takeaways

When designing wearable technologies for school environments:



Involve *all* stakeholders in every step of the design process

Consider pre-established dynamics of the environment

Cognitively scale activities based on age and ability

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