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Data in Motion: Sports as a site for expansive learning

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ABSTRACT

Background and Context: Sports and technology are often pitted as being at odds with one another. While there are several educational activities that make reference to sports we seldom see sports used as an authentic context for learning computing.
Objective: We describe the design of Data in Motion, a curriculum that considers the bi-directional opportunities for sports to improve learning of STEM and for STEM to help improve participants' athletic performance.
Method: We implement Data in Motion as a five-day summer camp with 33 participants, grades 2–6. We observe the ways that the experience changes students' perceptions of the connection between sports and technology through student surveys, observations and artifact analyses.
Findings: Across the pool of participants, we saw significant changes in the ways that students conceptualized the connection between technology and athletic performance. We also saw students who are not interested in sports demonstrate high engagement in the experience.
Implications: Practice-linked learning, specifically in the context of sports and technology, is a generative space for students to authentically explore interests in both disciplines. Researchers and practitioners should consider this intersection as a potential space to broaden modes of participation in computer science.

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Introduction

Under current educational and societal structures, the ways that people should "do" and learn computer science often fall into rigid categories that leave little room for expansive ways of knowing (Bang & Medin, 2010; Harel & Papert, 1991; Philip & Azevedo, 2017). Frequently, models of K-12 computer science education involve individualistic learning activities (Lewis et al., 2016; Wang et al., 2017), rely on direct instruction (Adams & Engelmann, 1996; Newell et al., 1967), and involve decontextualized and esoteric assignments (Webb et al., 2012). This style of learning is misaligned with the more collaborative and creative ways that computer science is used in practice (Papert & Resnick, 1995; Peppler & Kafai, 2007; Resnick, 2002). In an effort to democratize access to computer science in K-12 settings, online courses (Zeid et al., 2011), coding bootcamps (Brandt et al., 2010), college outreach programs (Tangney et al., 2009), after school programs (Schanzer et al., 2013), and

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summer programs (Wagner et al., 2013) have emerged. Many of these programs focus on creating pipelines for more youth to go into Science, Technology, Engineering and Mathematics (STEM) careers, rather than focusing on what computing means for their current learning. We posit that, with adequate pedagogical support, computing can be a tool that youth use to investigate what they know now and what they want to know in the future.

Many existing programs do not adequately support marginalized youth (Margolis et al., 2003). This permeates many K-12 settings where marginalized youth may be guided away from computing experiences or be situated in a school district where there is no access to these opportunities (Goode, 2007; Hill et al., 2010; Pinkard et al., 2017). Out-of-school computing experiences are typically concentrated around areas of wealth and in neighborhoods where parents/guardians have the time to research opportunities for their youth (Craig Watkins, 2011; Margolis et al., 2003; Warschauer & Matuchniak, 2010). Furthermore, STEM media propagates narrow images of who enters computing spaces. This biases youth, and, at times, their teachers, away from learning opportunities related to technology and computing (Cheryan et al., 2013). Therefore, when designing and framing computing environments we must be intentional about supporting youth from all backgrounds.

Data in Motion is a program that democratizes applications for computing by inviting youth to investigate relationships between computing and their athletic goals. With this work, we encourage the use of computer science educational spaces to provide youth with tools to facilitate inquiry and enacting change in their environments. In this paper, we expand upon current models of computing through discussions of the design of expansive STEM learning environments. To do this we detail how relationship building and designing wearable technologies in a practice-linked environment constitute effective ways to engage youth in personally-meaningful and engaging computing experiences.

Most youth have intimate relationships with sports. We have seen these relationships first-hand, with students working at great length to superficially connect their class projects, in media arts and music, to sports. Students seldom have opportunities to deeply connect sports with learning. Integrating technology and computing into the context of sports, provides an opportunity for students to experience bi-directional learning. This bi-directional learning is taken up in the form of critiquing, designing, and asking questions about technology to improve their sports performance and using sports as a space to concretize abstract concepts in STEM. This paper presents an expansive computer science learning environment design that acts as a potential model for future work aimed at fostering bi-directional learning between sports and computing.

Purpose

The purpose of this work is to expand student perceptions of computing by inviting them into an experience that demonstrates generative connections between computing and sports. These expansive learning environments can celebrate a variety of people's knowledge and experiences, unique to how they navigate life, that may traditionally be viewed as deficits. With this in mind, we emphasize continued exploration and advancement in youth passions of sports and situate technology as a resource in helping students attain their goals. Additionally, rather than encouraging youth to associate technology with intrinsic benefits, or heralding it as the intervention that youth need, we take up the work of Philip et al. (2013) to encourage critiques of technology and assumptions about the positive role of technology in society.

Our analysis of Data in Motion centers around the question, "How do students perceive, instantiate, and experience practice-linked learning at the intersection of sports and technology?" Answering this question will help ascertain the value of these types of expansive learning environments and motivate on-going work at this intersection of sports and computing.

In the remainder of this paper we provide theoretical foundations and relevant work that support the design of Data in Motion. The prior work also surfaces suggested methodological approaches for evaluating Data in Motion. We then move into a description of the program structure and begin our presentation and analysis of how students experienced Data in Motion. Finally, we discuss how the experiences of Data in Motion cultivated bi-directional connections between technology and sports and suggest some implications of this work.

Theoretical foundations

We position Data in Motion's theoretical grounding within prior work on sports learning environments and expansive forms of STEM learning environments. First, we position the practice-linked learning that occurs within sports as a contributor to deep engagement. We then discuss expansive STEM learning environments that support multiple ways of knowing and conclude by positioning athletic environments as a place for this expansive STEM learning.

Sports as legitimate learning environments

There has been a great deal of work examining the relevance of sports in young people's lives. At the core of many of these discussions is the idea that sports are an example of practice-linked learning environments (Nasir & Cooks, 2009; Nasir & Hand, 2008). In conceptualizing practice-linked learning we refer to Nasir and Cooks (2009) work with youth track hurdlers, which articulates "learning to be shifts in the use of artifacts (both cultural and cognitive) for problem solving, sense making, or performance" (Nasir & Cooks, 2009, p. 44). Furthermore, this learning is mediated by material, relational, and ideational resources, which contributes to youth identity development (Nasir & Cooks, 2009). The practice-linked environment of sports has material resources such as balls and jerseys, relational resources based on relationships with teammates and coaches, and ideational resources such as understanding what it means to be a "jumper" or a team captain. In Data in Motion, we consider pedagogy and technological devices as material resources, relationships between youth, coaches, and the research team as relational resources, and asking questions about sports performance as an ideational resource. This, we hypothesize, provides opportunities for students to simultaneously move towards positive identities in sports and computing.

In Nasir and Hand (2008), the authors contrast the ways youth participate in basketball with mathematics class. They surface the ways that participating in basketball was able to promote deep engagement that was not always the case in the mathematics classroom.

They also identified three dimensions of sports-related environments that promote deep engagement: access to the domain, integral roles, and opportunities for self-expression (Nasir & Hand, 2008). Access to the domain refers to the precise ways that students are able to articulate the skills and practices needed to be proficient in basketball. It also encompasses the explicit types of feedback and instruction that players receive from coaches and teammates and the ways their mistakes impact the short-term and long-term success of the team. Integral roles refer to student awareness of their individual and collective roles on the basketball court. This includes both performance roles (e.g. being a rebounder, or scorer) as well as social roles (e.g. being a leader or providing verbal support to teammates). These roles are important for giving students a framework to evaluate how they are developing. Finally, opportunities for self-expression are exemplified in the ways that athletes can bring their own style of play to a given position or attempt to mirror the style of their favorite player. Thus, basketball, and sports more broadly, can be positioned as a transformative learning environment that features practices that foster deep engagement.

Expansive STEM learning environments

The apparent separation between STEM and conversations of politics, race, class, and culture has led to monolithic definitions of STEM practices (Bang & Medin, 2010; Vossoughi & Vakil, 2018). While technology becomes increasingly pervasive, a simultaneous refusal to hold these conversations does a disservice to youth and communities at large. In designing culturally relevant STEM environments, we must allow for epistemological pluralism (Harel & Papert, 1991), or different ways of knowing and thinking about the world (Bang & Medin, 2010; Philip & Azevedo, 2017). This leads to learning environments that utilize technology as a tool that might help us answer, or become a site of critique to investigate, questions that we have about the world. If we design STEM learning environments that assume that students hold one view of computer science knowledge, we neglect the everyday computer science we experience in our communities (Tan et al., 2019; Warren et al., 2001). For example, rather than applying "the scientific method" to investigate a family recipe, a caregiver might explain to a child how all the ingredients nourish them and why they combine them in that way. This is not to say that integrating technology into environments always benefits learning, but rather, when integrated with strong relationships and pedagogy, it can afford new learning pathways (Garcia, 2017).

Practice-linked learning environments, such as sports, dance, cooking, and music, afford opportunities for youth to investigate how their interests and ways of knowing come into conversation with technology. Music, specifically hip hop, has been a tool of political critique for many Black and Brown hip-hop artists. For example, Tucker-Raymond et al. (2018) help youth critique the world around them and provide simultaneous outlets for creation. We assert that within the learning domain of sports, there is potential to discuss politics, race, class and culture while simultaneously engaging with technology. For example, students might discuss Colin Kaepernick and how he uses his platform for political ends. They might also ideate about how technology supports or corrupts those political agendas. Sports, therefore, can provide a space for youth to connect to different contemporary and historical social, cultural, and political topics. Furthermore, broadcasts of professional games, statistical analyses of players, and use of wearables in training camps are linked to advances in technology. This provides fertile ground for discussions of how technology is used within different areas of athletics. Additionally, since technology cannot be used to answer all questions athletes have, it raises sobering ideas about the limits of technology and computing.

Related work

In this project, we build upon the above theoretical frameworks as well as an existing body of literature on using wearables for learning, and the exciting educational opportunities that exist when designing wearable e-textiles.

Wearable technologies

Youth creating wearables and e-textiles are examples of how constructionism (Papert, 1980) offers methods for empowering users of a variety of backgrounds to create the solutions they imagine (Katterfeldt et al., 2009). Work by several learning scientists have supported the need for personal expression within the digital fabrication and invention, or Maker Movement. To advance this mission, Buechley et al. (2008) created the LilyPad Arduino, a modification to the popular hobby microcontroller, that readily allows users to embed electronics into clothing items. For example, students have used LilyPad Arduinos to make shirts with intricate LED designs that would illuminate at the push of a button or when there was little light within the room. This platform has been powerful for allowing youth and hobbyists to create new wearables and e-textiles.

The EduWear project, which implements e-textiles for learning, reports on the centrality of empowerment as a critical element of 10–14-year-olds learning (Katterfeldt et al., 2009). Katterfeldt et al. (2009) further position empowerment as a core commitment of constructionism. Another fundamental design component of the EduWear project was to create an environment that elicits the personally meaningful affordances of e-textiles for young people. The results indicated that this type of workshop provided opportunities for young people to design personally meaningful e-textiles based on their own areas of interest and/or problems they faced in their day-to-day lives. The youth involved in the study increased confidence with technology and programming through their participation in the workshop.

In a complementary line of research, Ngai et al. (2013) developed i*CATch, a wearable construction kit. The authors report on six studies that took place in camps, workshops, and higher education courses with participants ranging elementary school students to graduate students. The studies were intended to explore the potential for the construction kits to allow “novices” to use them under appropriate guidance. The software driven kits aim to simplify aspects of building wearables by requiring only rudimentary craft and engineering skills. The researchers found the kits to be successful in facilitating engagement of nontraditional students as well as providing an economically accessible construction kit that was reusable and durable.

Collectively, these related works, point to ways that researchers have used wearables as a meaningful context for helping students think about data and answer personally meaningful questions about their physiology and their use of certain gestures. Similarly, the work with e-textiles has made evident the power of constructionist learning experiences to also provide meaningful and empowering interactions. In this paper, we build on these ideas and describe a program that bridges pedagogical opportunities with wearables for improving learning and athletic performance and the empowerment associated with students designing and building.

Learning, wearables and data science

Researchers have suggested that youth need to learn multiple ways of generating, interpreting, visualizing data, and ethically using data (Pangrazio & Selwyn, 2018; Prado & Marzal, 2013). Throughout this research there is an emphasis on youth engaging with and learning data that reflects their cultural environments, lived experiences, and knowledge (Ching et al., 2016; Maybee & Zilinski, 2015). In looking at work by leading researchers, we see a number of examples that move the discussion closer to the realm of data science and utilizing wearables to answer personally meaningful, data-driven questions.

Kang et al. (2016) discuss their work to co-design and implement a system that provides real-time visualization of whole-body and group movements. Their system, SharedPhys, represents a collection of prototypes developed to allow elementary school children to visualize and reflect on topics ranging from human physiology to basic statistics. The team tested the platform at an after-school program for elementary students and found that participants demonstrated an increased awareness of their body physiology after engaging with SharedPhys. Their analysis is based on a combination of participant observations and survey feedback. In summary, their analysis highlighted ways that both students and teachers found this type of interaction to be engaging and potentially have a positive impact on STEM learning.

The work of Lee and Drake (2013), (2015) and (2019) also provides useful insights for designing and studying learning with wearables. Their work involves students using fitness trackers, heart monitors, and hip-based step counters while participating in athletic activities during recess. Wearables strengthen students' learning and understanding of numbers when they produce the data themselves (Lee et al., 2015). Additionally, the researchers' analysis surfaced ways that the experience helped students create narratives around their data, and supported investigation of personally motivating questions. To this end, students developed and practiced authentic data cleansing, data analysis, and question generation. Lee et al.'s (2015) study was designed to show that wearables promoted healthy exercise habits and show the potential for contextualizing and supporting teaching and learning in science and mathematics. Lee et al. (2016) utilized wearables during physical education to teach students in grades 3–8 about data accuracy and statistics related to physical education. Finally, Lee et al. (2019) explored how students' thinking and behaviors may shift when they learn about data through their use of activity trackers and other wearable devices. Methodologically, this work uses a combination of pre- and post-questionnaires and participant observations that informs the analyses in this paper.

In a complimentary line of work (Ching & Hagood, 2019; Ching et al., 2016), researchers describe learning experiences that bridge activity monitoring, games, and science education. Broadly speaking, the papers advocate for more research on the use of personally meaningful learning with wearable devices. This is an essential element of Data in Motion and similarly borrows from the principles of constructionism. These papers describe experiences and reflections from middle school students using pedometers and a virtual game that rewards them for being physically active. Ching et al. (2016) presents different categories of emergent resistance on the part of participants. These categories of resistance stem from a combination of factors that are a function of the device or the result of user error. Ching and Hagood (2019) analysis suggests that students' perceptions of "accuracy" often conflate errors with the device and human errors in data collection. However, long-term participation with the devices gave students experiences and examples to concretely discuss the source of the different errors. We build on this idea in Data in Motion by having students intentionally take actions that will result in data inaccuracies.

Another important perspective that emerges from Ching and Hagood (2019) is the use of constructionism to analyze student learning. Their analysis focuses on student knowledge generation and knowledge reformulation. Knowledge generation refers to the novel ideas and insights that students may garner during their participation in a given learning experience. Ching and Hagood (2019) identify knowledge generation through focus groups, interviews and observations. We use surveys to assess students' perceptions of their knowledge generation, in conjunction with our observations and one-on-one interactions with students. Knowledge reformulation, often viewed as more difficult than knowledge generation, takes the knowledge and puts it into action. In our analyses, we will utilize student generated artifacts to carefully consider the ways that students took the new ideas and put them into practice.

Finally, recent work by Hardy et al. (2020) promotes a framework for engaging high school students in learning experiences that bridge science, physical computing, and answering personally-meaningful questions. Core to their framework is the idea that data is not neutral and reflects the intentions of the device's designer. Accordingly, they advocate for students to exercise agency in the design of the data collection devices, and in the questions being answered. This approach allows for a certain level of idea emergence that closely aligns with the actual practices of science. While Hardy et al. (2020) operates within a different context than the current work, we find several points of alignment between their framework and how we approached this project.

These projects speak to the compelling nature of physical activity as a vehicle for learning and to the vast opportunities to leverage both custom and off-the-shelf wearables. They also provide guidance on studying young learners' engagement and enjoyment of these experiences.

Data in motion program design

Data in Motion is a program designed to facilitate young people making connections between athletics and computing. Based in the rich learning environment of athletics (Nasir & Hand, 2008; Turman, 2003), Data in Motion combines individual and group activities to engage learners in an experience that is authentically athletic and computational. We want to show participants of Data in Motion what alternative configurations of computing environments can look like. These alternative configurations are collaborative, inquisitive, and supportive of learning without judgment. Below we outline our design process, technology and activity design, and provide a sample schedule of activities.

Design process

The current design of Data in Motion is the result of years of ongoing interactions and pilot testing with local youth. During our earlier work with a local middle school, we noted that many students had significant interests in sports. Regardless of the specific project or activity medium (e.g. picture, report, video) students would elect to center sports as the project's focus. Unfortunately, many of these points of integration were superficial and limited. Seeing the desire youth had to combine sports in a variety of subjects, we began developing Data in Motion. Over the course of three months we identified a set of wearable sensors and complementary activities for local youth. We then spent six weeks testing some of these wearables and activities at an after-school program in a makerspace. A key insight was the need to keep the activities relatively self-contained. This meant that the activities needed to be short and not dependent on the previous activities. Given the informal nature of afterschool programs, student attendance can be variable. Secondly, the technologies needed to provide real-time data visualization and interaction. Students did not want to wait to view their data. With these insights and prior research in mind, we formalized a schedule for the week-long summer program.

Technology and activity design

Table 1 presents a schedule of activities that we used for Data in Motion. We designed our activities to leave room for youth to explore their own learning goals within each activity. We found that having both structured and unstructured activities would allow youth agency over the learning goals and adequate time for the team to support them in gaining the appropriate technical skills to further their goals. While many technologies and activities supported multiple goals, below we place them within an overarching framework that explains how they met that goal. A more detailed description of each activity and curriculum can be found in the supplemental online info (See Appendix A, which includes snapshots of the technology in figures A1-A6). We include Tables 2 and 3 to illustrate how these activities break down within our intended learning goals.

Playing with wearables. Throughout Data in Motion, youth had the opportunity to explore a variety of wearables such as Pozyx indoor position tracking, Wear OS smart watches, and the Spalding Smart Shot. The Pozyx system allows for live indoor location tracking in relation to ultra-wideband anchors that designate the area of a space. Participants wear a Pozyx tag with a specific identifier that enables them to see their spatial location on the court. Paired with live visualization via a custom Python script,

Table 1. Summary of activities by day.

Activity	Monday	Tuesday	Wednesday	Thursday	Friday
Playing with Wearables	x				
Android Watch Sensor Challenge	x				
Impossible Game Ball	x	x			
XYZ Racing		x			
Drills with Wearables		x			
Wearable deconstruction and critique			x	x	
Introduction to Physical Computing			x	x	x
Project ideation			x	x	x
Tap the flag					x

youth playing basketball can see where they are on the court in real-time. Youth can also see their total distance moved and maximum velocity. After open exploration, they played 5-on-5 basketball games and had the opportunity to critique device wear-ability and ask questions about how Pozyx works. Youth also interacted with a smart watch app that displayed three-axis acceleration, three-axis rotation and steps taken. The app could also be configured to vibrate based on single- or multi-axis movements. We prompted youth to determine what actions made their watch vibrate and supported them in using a coordinate plane to describe the motions. Students were also challenged to use the step tracker to increase their step count without taking steps and to take as many steps as possible without having the step count increase. Additionally, students practiced athletic drills with the watch while checking the magnitude of their gyroscope or accelerometer data. One drill included shooting free throws with their dominant hand and their non-dominant hand. They collected that data and compared and contrasted the results. Through these activities, youth were exposed to some of the ways that current wearables behave and what common sensors might tell us in a sporting environment.

Asking and answering questions. In addition to the question's youth generated during the athletic drills, we facilitated youth inquiry while playing with the Impossible Game ball. This ball contains sensors that can track spin, vertical height, catch force, distance thrown, and more. This data is transmitted in real time to an iPad, Android or Windows App and can be viewed in real-time. Youth completed group challenges such as throwing the ball to each other with the lowest catch force. Youth were encouraged to explain how they thought the design worked and were supported in bridging between their understanding and how the app actually worked. The facilitation team was careful not to use statement-based language or label things as wrong or right. During smart watch sensor play, the facilitator's approach was to ask guiding questions that pushed youth to deepen their understanding.

Exploration of physical computing. Students explored physical computing through the lens of embodied interactions and the use of low-cost microcontrollers. We introduced the idea of prototyping on physical devices with block-based coding using a GoGo Board. The GoGo Board Sipitakiat et al. (2002) is a low-cost microcontroller with sensor and actuator ports and a built-in display for sensor values and other messages. This board can be plugged into a standard USB battery pack or plugged into a computer and programmed in a block-based environment. Activities included plugging in sensors and investigating what high or low values indicated for each sensor. We led them through programming an interaction using their knowledge of different sensor values, such as having an LED light up when it was raining as indicated by the humidity sensor.

Ideating and Redesign. This was a multi-day process that included critique, ideation, and redesign. It also included a synthesis of the three previous activities, as each one contributes to the student's design process. In this section, we focus on ways that we engaged students in critique, ideation, and redesign.

An existing commercial wearable, the Spalding Smart Shot, was used as the basis of youth critique and design deconstruction. The Smart Shot is marketed as a tool that can improve a user's shooting form in basketball. Students tested the device and collaboratively identified flaws in the user experience. After engaging in a critique, youth took the device apart to reveal its internal components: an accelerometer, a speaker, an LED, and a battery. This was an opportunity to provide a concrete visual of what was powering the Smart Shot. To further support student understanding of the internal logic of the Spalding Smart Shot, we developed a smart phone app that mirrored its capabilities. Talking through how this app worked illuminated the underlying mechanics of the Smart Shot. Additionally, by showing the youth it was programmed using block-based code, the team validated the utility of block-based programming for designing real applications. Finally, to support further ideation and redesign, students discussed ways that the Spalding Smart Shot could be improved. When coupled with the prior and concurrent activities of asking and answering questions and exploration with wearables, we believe that these activities would be strong ideational resources for developing personally relevant, sports-related wearables.

Table 2. Technology by category.

Playing with wearables	Asking and Answering questions	Exploration of physical computing	Ideating and Redesign
Ultra-wide band indoor location tracking	Impossible Game Ball	GoGo Board	Spalding Smart Shot
Smart Watches	Smart watches		Homecourt.AI
Tap the Flag			Android Smart Shot

Table 3. Activities by category.

Playing with wearables	Asking and Answering questions	Exploration of physical computing	Ideating and Redesign
Playing with Wearables	Android Watch Sensor Challenge	XYZ Racing	Project Ideation
Drills with Wearables	Impossible Game Ball Challenges	Introduction to Physical Computing	Wearable Deconstruction and Critique
Tap the Flag Game			

Table 4. Survey questions.

Survey Question	Pre	Post	End of Day
How much do you like sports?	x	x	
How much do you like USING technology?	x	x	
How much do you like BUILDING technology?	x	x	
Can sports help you with math or science concepts?	x	x	
Can technology help you do better in sports?	x	x	
Today's session was (very boring to very fun)			x
I would be interested in doing these activities in school:			x
I learned something new today:			x
I learned something interesting today:			x
I am looking forward to tomorrow's activity:			x
Do you plan on continuing your project?		x	

Study

Participants

In this study, we worked with a local community group that facilitates youth making healthy food choices, playing, and staying active. Activities were held at a local community center's basketball court, classrooms, and outdoor fields. Our participants were members of a suburb of a large midwestern city in the United States. The 33 youth in this program were rising second to sixth graders. The participant demographic composition included 21 Black girls, 3 Latina girls, 8 Black boys, and 1 Latino boy. Though not described in detail, high school mentors/coaches from the program participated in many of the activities as well.

Research team

The research team for this study consisted of a professor, doctoral student, and master's student at a nearby university. The professor is an engineering and education researcher with prior experience as a collegiate student athlete and youth soccer coach. This prior experience informs the activity design. The doctoral student is an engineer, who has prior experience working with youth and supporting technological sense making. The master's student is a computer scientist, who ran track in the past and leads an active lifestyle. All three research team members are Black; two members are men and one is a woman. The alignment between the ethnic identity of the research team and the student participants is, in itself, an intervention on the practices of computer science education. Namely, engaging youth in computing experiences led by three Black researchers, who also engage in athletics, already begins to disrupt traditional notions of who participates in computing and sports.

Data collection and analysis

The analyses in this paper are based on a combination of student surveys, student-generated artifacts, and field notes. Each of these pieces of data help us answer our research question in different ways. The survey data gives a high-level view of student perceptions and how they experienced the program. The student artifacts help us see how students instantiated their learning, and the field notes give a more detailed picture of a student's experience across different portions of Data in Motion.

Surveys

Students began the week with a pre-survey and ended with a post-survey (Table 4). The surveys were anonymous and optional. The pre- and post-surveys asked the following questions: How much do you like sports? How much do you like USING technology? How much do you like BUILDING technology? Can sports help you with math or science concepts? Can technology help you do better in sports? Each question is linked to student perceptions that might influence how they experience the program. Changes in student responses to these questions could reflect ways that the program altered their perceptions. For each question, students could select from a 4-point Likert scale with items ranging from “not at all” to “a lot.” In the post-survey we additionally asked if youth were interested in continuing to work on their projects after the program concluded. Students had the option of indicating yes, no, or maybe. Elements of the survey are influenced by Blikstein et al. (2017) and the STEM Activation Framework (Dorph et al., 2016), two validated measures for looking at student literacy with technology and their perceptions, values, beliefs, and choices concerning STEM.

Throughout the week participants also answered daily surveys. These were administered at the end of each session to gain a sense of student interest in the activities. These daily surveys also provided the research team with feedback on how to make adjustments for the next day’s activities. For these check-ins, students were asked to indicate if that day’s activity was interesting, if they learned anything interesting, and whether they’d be interested in doing the activity in school. This approach of collecting student data reflects prior work in understanding young children’s perceptions of technological designs (Kang et al., 2016; Lee et al., 2019).

The student survey responses were translated into an ordinal, numeric scale. The pre- and post-survey responses were compared using a one-sided T-test. Because all survey responses were anonymous, no paired tests were used.

Student-generated artifacts

A primary component of this program was the iterative ideation of student-generated wearable devices. The artifacts were ideated and refined over the course of three days during the second half of the week. Some students worked individually, while others worked in small groups because there was significant overlap in their problem or solution areas. As part of this process students developed different written and sketched artifacts.

An iterative approach was used to look for themes in student prototype design. A pair from the research team discussed potential initial categories, which were then re-evaluated with a third member. Data in Motion student participants offered initial category suggestions around tracking progress and giving feedback to the wearer which became refined into the four categories discussed in the findings.

Field notes and ethnography

The team wrote notes summarizing each day’s experience and evaluating the ways pedagogy could be enhanced to support the technological tools being used. The research team debriefed after each session to understand what could be improved for the next day.

The specific student that we discuss, Vero, was selected for ethnography because she is a part of a study on the ecosystem of innovative learning experience within this mid-western suburb. She was also among a small group of students who were not intrinsically interested in sports. Thus, by focusing on Vero’s experience we can examine how a student who does not identify as a sports enthusiast experienced Data in Motion. Using the field notes and debrief meetings, we checked for themes that were emergent about how Vero experienced the space.

Findings

As we begin to make sense of the data, we return to our research question: "How do students perceive, instantiate, and experience practice-linked learning at the intersection of sports and technology?" We begin this section by looking at student perceptions as gleaned from the survey responses. We then move into a presentation of the student artifacts and conclude with a closer look at the experience of a student who was not motivated by the sports component of Data in Motion.

Interests and perceptions – athletic, technology enthusiasts

The pre- and post-surveys provide insights into student self-reported interests in sports, technology, and ideas at their nexus. 21 students completed the pre-survey on day one. One student opted not to participate, while several others were absent. Twenty-seven students completed the post-survey.

Table 5 contains a summary of the pre- and post-survey results. Students generally reported being interested in sports and using technology. Students were less inclined towards building technology and also seemed skeptical that sports can play a role in helping them understand concepts from math or science. Their skepticism was even greater for the question about technology being able to improve their athletic performance. The average score of 2.285 was the lowest score for any question on the pre- and post-surveys. Generally, we see that students self-identify as technology consumers who enjoy participating in sports, but who do not see much of a connection between sports and academic endeavors.

Shifting perceptions on the links between sports and computing

From pre-test to post-test, most of the survey measures remained unchanged. There was a slight decrease in student self-reported interest in enjoying sports and slight increases for three of the other measures. However, none of these results indicate statistically significant differences. For example, There was no difference in student enjoyment of using or building technology ($t(44) = 0.63$ $p = 0.265$). However, the survey results did surface important information about student perceptions of technology being useful for improving athletic performance. On Monday, students reported having little to no awareness of potential connections between sports and STEM. On a four-point scale, ranging from "not at all," to "a little," to "some," to "a lot," the modal response was "a little." In contrast, on Friday, the modal response was "a lot." This shift was also noted through statistical analysis with students' scores on Friday ($M = 3.22$, $SD = 0.87$) showing a greater

Table 5. Average pre- and post-test survey results.

Question	Pre	Post
How much do you like sports?	3.62	3.48
How much do you like USING tech?	3.29	3.38
How much do you like BUILDING tech?	2.71	2.85
Can sports help you with math or science concepts?	2.67	2.85
Can tech help you improve in sports?	2.29	3.22

(t(45) = 3.41, p =.001) awareness of the connection between sports and technology than they did on Monday (M = 2.29, SD = 0.98).

Perceptions of data in motion

We now transition to looking at student perceptions of Data in Motion through a brief presentation of daily survey data and post-survey data. Recall that the daily surveys asked questions about student enjoyment and learning from the activities that day. A selection of these results can be found in Figures 1–3.

The results from daily surveys point to general student satisfaction with the program (Figure 1). Across all sessions students consistently report having fun, learning, and finding the activities to be interesting. This was most notable on Thursday and Friday, the physical computing days, with over 50% of participants responding favorably to questions about learning (Figure 2), interest, and enjoyment. Additionally, participants expressed an interest in having several of the activities as part of their in-school experience (Figure 3).

The final point of corroboration of student self-reported interest and enjoyment of this learning environment comes from the post-survey. Namely, students were asked if they intended to continue working on their project after the conclusion of the summer program. Seventy percent, or 19, of student respondents indicated that they plan to continue working on their project ideas.

The quantitative results provide a general picture of the student participants and their perceptions and interests. However, this data omits the rich ways that students apply these new ideas. The next section will address this question by presenting the ways that students conceptualized synergies between technology and sports as manifested through their project designs.

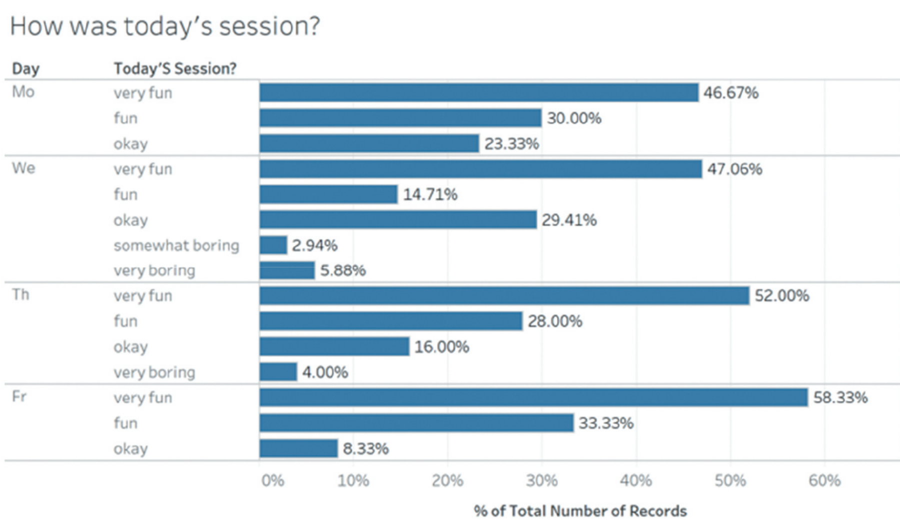

Figure 1. Students perceptions of data in motion by day.

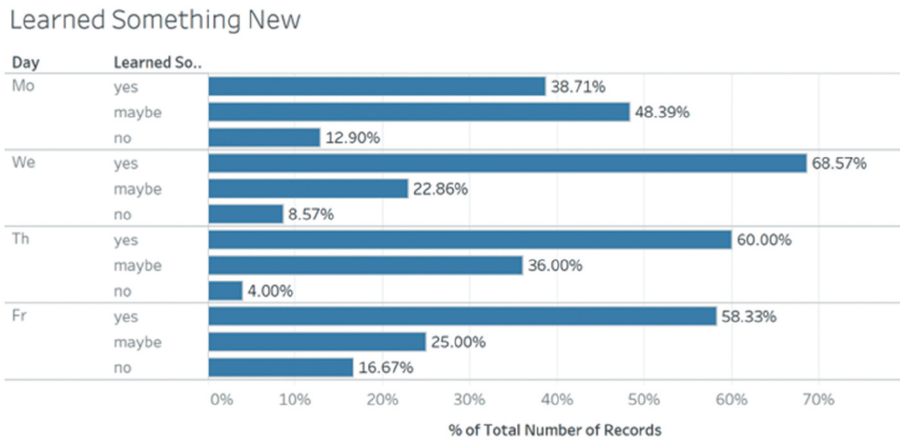

Figure 2. Student perceptions of learning something interesting.

Student generated-artifacts

One way for concretizing student growth is by looking at the types of project ideas that emerged at the conclusion of the week. In the beginning of the week the connections students drew between technology and sports centered around those in television broadcasting. For example, students noted that technology can help you keep track of the puck when watching hockey or showing viewer the first down line in football. These two examples of technology being used in sports fall short when compared to the project ideas generated by the students. They are distinctly different from the student generated projects in two ways. First, the ideas suggested at the beginning of the week by a small number of students were merely about surfacing information to spectators and had no immediate connection to improving athletic performance. Second, the examples from professional hockey and football are far removed from the reality of youth athletics, both in terms of it being for professionals, and in terms of it being mediated through a television screen. In contrast, the ideas that the students developed are centrally focused on improving athletic performance, are closely tied to the youth athletic experience and are physically accessible to them.

Student designs came from brainstorming around prompts such as “What would you like to improve about your sports performance?” and “What type of feedback (vibration, sound, light) do you think would work well for your device?” It would be intractable to discuss each of the youth project ideas in detail. Instead, we coded each project and assigned it to one of four categories. The creation of these four categories was influenced by the ways that youth thought about the different types of projects that they could pursue and were refined by the research team. These categories include: Health Monitoring, Action Automation, Progress Tracking, and Form Awareness. Some of these categories have clear ties to the activities that students completed in the summer program, while others are fairly novel idea spaces. Additionally, the categories are not mutually exclusive.

Health monitoring

Health Monitoring is a category that was scarcely discussed during the camp, but that potentially has ties to recent media reports on heat stroke and heat exhaustion among collegiate and professional athletes. Three student projects were categorized into this category. Projects in the health monitoring theme would alert the player when they are engaging in a practice or set of actions that may be unsafe. For instance, one student proposed a health monitoring wearable for football players. Their wearable would be embedded within the helmet to monitor sweat levels and skin temperature. This student wanted to prevent football players from suffering from heat stroke by using the collected data to send hydration reminders and notifications to cool down. This device was outside of the range of wearables the youth had experienced in Data in Motion but inspired by work with the GoGo Board. Upon understanding the potential for a sensor to measure water levels, the student innovated and ideated a sweat sensor for their helmet.

Action automation

Devices we call action automation, are wearables that rather than suggesting improvements in performing a motion, complete the motions or action for the users. These students were reimagining what computing might look like when used in athletics. This idea space was also one that we did not explicitly discuss through our activities. Nonetheless, Data in Motion was able to provide space for youth to set goals and reinvent what a solution to that goal might be. Two of the final projects were labelled with action automation.

Both action automation designs were from groups of students who were learning or struggling with aspects of swimming. In initiating their designs, one student stated that they struggled with staying afloat while performing the backstroke. They then proposed a device that would move their arms with the correct form and therefore prevent them from sinking underwater (Figure 4). Another student similarly listed staying above water being their most difficult task. They designed a pair of buoyancy pants that reacted based on water levels. The water sensor embedded in the pants would inflate automatically and prevent sinking. Work with the GoGo Board became a space to prototype this idea. The students used the water sensor to test out their device's logic, setting a threshold for response based on a water level, and imagining what kind of mechanisms would be required to inflate the pants.

Progress tracking

Five student groups created progress tracking devices that recorded and measured statistics like distances, time, and steps. As facilitators, we understood many of these functionalities to be available in the commercial smart watches students had interacted with throughout the program. When asked if the smart watches could solve their problems, they expressed a sense of disbelief. Part of this may be the inaccessibility of smart watches for these youth. None of the youth wore watches, and few had interacted with smart watches outside of this program.

Example devices that students designed included monitoring speed when they are running and tracking how long they swim. They wanted to be able to keep a record of their top speed and times in order to challenge themselves to continue improving. The drills with wearables activities may have contributed to this idea space by including accelerometer and gyroscope data for free throws on dominant and non-dominant hands.

Form awareness

Our final and most popular category, Form Awareness, describes wearables that would provide participants with added detail on their form or technique. Nine projects were placed in this category. Form awareness constitutes a range of devices that include alerting the user when to perform an action and describing the performance of a specific action. One student focused on gymnastics form, imagining using the gyroscope to detect whether the user twisted or kept their body straight while doing a backbend or back handspring. Other students built on concepts from the shot trainer activity to create wearables that provide more in-depth information in basketball.

To conclude this section of student-generated wearables, we will walk through the ideation process with a concrete example of a basketball-focused group. This group created a basketball wearable that alerts players when they are free to shoot, which direction they should head on the court, and plays music when open to receive the ball. On Wednesday before coming to this design, they spent some time brainstorming what they would like to improve in their game (Figure 5). These skills, including looking out for passes and knowing when to shoot, were then used to develop the features of their wearable. Facilitators asked questions about what kind of devices or sensors they had seen that week that they thought could be useful and what other sensor capabilities they might need. In order to know when to shoot, they needed to know where the other players were. They mentioned using features from the basketball court tracker (Pozyx system) to determine distances from other players. However, they also wanted to notify the user on their smart watch if they are open through both music and vibrations which required additional sensors to be embedded into the watch. Thursday, after they experimented with the GoGo Board, they sketched out a prototype of their design (Figure 6). On Friday, they continued to experiment with this GoGo Board to refine the types of sensors they might add to their watch. We believe these examples highlight how students conceptualized this practice-linked environment. We find that students created a rich set of sports-related wearables that build and extend the types of devices that they used during Data in Motion.

But I don't like sports?

By positioning sports as a driving factor, Data in Motion risks alienating students that do not self-identify as sports enthusiasts. While our pre-test indicated that most students were interested in sports, it also reflects that some students are not drawn to sports. Because our goal is to be inclusive and provide a rich learning experience for all participants, we now turn to the particular experience of a student who was not drawn to athletics. Vero is an African-American rising sixth grader who has participated in STEM, dance, and African cultural activities throughout her community. She is a part of a local STEAM network where she had the experience of designing e-textile wearables and working on an app in XCode. Sports were not her primary subject of interest, but she decided to participate in the camp with a friend.

For six weeks that summer she participated in a STEAM camp for rising sixth graders where her final project was an app that navigated K-12 students to both educational and exercise-related activities. While frustrating at times, she said, "This really made me want to be a programmer." With her interest in programming, we saw opportunities to strengthen her ideas of what you can do with programming languages. However, as a sports-related camp we had some concerns about her potential overall enjoyment. We find that space for open learning goals, set by students, generally enabled Vero's continued engagement.

On the first day of the program we began with an icebreaker activity that asked students to identify their favorite athlete and imitate one of their signature moves. During this time Vero stepped behind a peer to seemingly avoid being called on. When it was finally her turn, she said "I don't have a favorite … do I have to do something?" With some additional questioning she said she guessed she liked gymnastics and did a cartwheel. After introductions, participants began playing basketball wearing an indoor location tracker. While Vero was interested in wearing the sensor, she was not as interested in the basketball game. When she noticed smart watches and the Impossible Game Ball on a table, she asked if she could try those out instead. As she tested the smart watch, she proceeded to try different dance moves to make the watch buzz and was excited when she figured out a set of actions that consistently generated high acceleration. Among the variety of activities made available through Data in Motion, Vero was able to find something that aligned with her interests.

On the second day, students were challenged to record their free throw acceleration and angular velocity data on their dominant and non-dominant hands. Vero was among the first students to get set up with a smart watch and begin the activity. She expressed genuine curiosity about how the accelerometer data was distinct between her dominant and non-dominant hands. She also approached the tasks with an eye for detail. Whereas many students tried to remember the different numbers in their heads, Vero's first step was to get a paper and pencil. She also partnered with another student to work together while recording data. After writing down her responses, Vero repeatedly engaged the facilitator and her peers with questions about why the values might be different. Within these discussions she proposed a number of ideas based on how shooting with one hand "felt different" from shooting with the other hand. Once again, even though Vero was not necessarily drawn to sports, she was one of the most engaged students in the Skills with Wearables activity.

Days four and five were equally as exciting for Vero as she was formally introduced to physical computing. On the fourth day of the program, students tinkered with different sensors on the GoGo Board. After getting comfortable with the standard set of sensors, which use 3-pin plugs, Vero noticed a motor, which uses 2-pins, and asked a facilitator how it worked. The facilitator directed Vero towards the actuator ports at the top of the GoGo Board and showed her how to connect it. Vero, however, was interested in using the motor as a sensor. She returned to the box of additional parts and began searching for a way to make it work. Her first attempt was to use wires to connect the pins of the motor to a sensor port. This did not work as she had hoped and resulted in her returning to the box to search for more materials. After some additional searching, Vero found an adapter that converted between 3 pins and 2 pins, allowing her to use the motor in a sensor port. Upon making this work, she ran over to the facilitator to share her discovery. Her face beamed with excitement as she said, "I got the motor to work." The facilitator congratulated her on figuring out her own challenge and encouraged her to show her peers.

In the final day of the program, while many students were busy wrapping up with paper designs and figuring out additional sensors they might use, Vero remained invested in exploring the affordances of physical computing. For her final project, she proposed using a smart watch with accelerometers to help her hit the ball better in volleyball. She created a basic sketch of this idea but seemed far more excited in continuing to tinker with the GoGo Board. Concretely, the GoGo board helped surface new ideas about what code can do and where it can go. For example, we asked Vero what happens to the programs she uploaded to the GoGo Board after the board was disconnected from the computer. She said that "they probably wouldn't work anymore." When she tested it, she saw that the program was preserved on the memory of the board. Despite having considerable experience with programming for her age, Vero noted, "I haven't seen that before" and shared her discovery with peers. As we discussed this with Vero further, we learned that while she had done a lot of programming on a computer, the programs never had much of a manifestation outside of the computer nor did the program persist when the computer turned off. To see physical computing disrupt that paradigm for what you can do with coding subsequently left Vero with new ideas about the possibilities of the world of computing.

Discussion

This paper contributes the design of an expansive learning environment and the student perceptions, experiences and artifacts that emerged through their participation. It suggests that the design encompasses a combination of curricular and pedagogical components that corroborate and extend prior work on constructionism, practice-linked learning and learning with wearables. We propose the integration of these approaches contribute to the positive outcomes reported within the results section. At the same time, the implementation of Data in Motion coincided with an expanded understanding of computing and sustained interest on the part of participants. These findings mirror and extend existing work on culturally responsive and expansive learning environments (Drazan et al., 2017; Margolis et al., 2015; Searle & Kafai, 2015). In this discussion section we will synthesize the emergence of these ideas across the different data we analyzed and connect it with prior research.

Cultivating an expansive learning environment

Personal relevance by design

Building on principles of constructionism, personal relevance and choice played a central role in the design of Data in Motion (Buechley et al., 2008; Harel & Papert, 1991; Katterfeldt et al., 2009). Students were presented with a varied set of activities and technologies to explore. With the support of the research team, participants were encouraged to tinker and critique the different tools, and subsequently build on them as they saw fit. Some activities included playing basketball, soccer, and catch while investigating how wearables could be used in these different contexts. Many student projects were motivated by these drills and activities, but still included important and meaningful modifications to make the overarching idea applicable to their sport of interest. This opportunity for youth to dictate both the tools and the goals of their projects, aligns with recommendations from Hardy et al.'s (2020) framework for promoting agency among youth. Personal relevance also provided a useful avenue for student engagement.

Vero's case study points to the critical role of personal relevance and choice. Despite Data in Motion building on best practices and experiences in sports, there was room for participants who were not motivated by the sports context to remain fully engaged. As we see with Vero, Data in Motion was sufficiently open-ended and student-directed to invite various forms of authentic engagement.

Fostering a culture of inquiry

Another driving and influential portion of the program design that connects to prior work was promoting inquiry and critique (Ching & Hagood, 2019; Kang et al., 2016; Lee et al., 2015; Tan et al., 2019). From the outset, the facilitators established a culture that encouraged inquiry and curiosity on the part of the students. They also established cultural norms that invited asking and answering questions. This was done by asking authentic questions and probing youth to reflect on what they observed or experienced. Perhaps one of the affordances of developing a curriculum that bridges two areas that are often viewed as disconnected is students feeling greater license to deviate from canonical practices and ideas of computing. For example, we saw students exercise significant deviations in creating devices that enable action automation and involve health monitoring. We designed Data in Motion to support these forms of inquiry and were pleased to see the extent that students felt comfortable and empowered to explore novel questions about using technology to improve athletic performance.

Collaboration, relationships and community

Embedded throughout the design and implementation of Data in Motion were opportunities for students to engage in a social and collaborative environment. This was present in the ways that activities were framed, but also in the ways that students, like Vero, shared their ideas and concerns with peers and the facilitation staff. This willingness to share their thoughts with the facilitation staff also signals a certain level of relationship development. As we previously noted, the facilitation teams and the majority of the participants shared the same ethnicity. We suggest that racial alignment helped accelerate the development of trust and comfort between the students and staff. Regardless of the racial make-up of the participants or facilitators, there is a strong need for developing relationships with the participants that move beyond the traditional teacher-student, or even coach-player, paradigms. The interactions with the facilitators also provided a window into the broader community of computer scientists (Friend, 2015; Lewis et al., 2016). Prior research emphasizes the role that relationships and multiple ways of approaching a discipline play in helping students see learning opportunities within those disciplines (Garcia, 2017). Overall, the design of Data in Motion included daily collaboration, trusting relationships, and an introduction to a more nuanced picture of the computer science community.

Extended understanding and interest in computing

The confluence of data suggests that our program successfully supported an expanded understanding of computing. This was observed across the survey results, student artifacts, and case study. From the pre- and post-surveys, we see that students began the week with little to no awareness of opportunities at the intersection of sports and technology but ended the week with a clear awareness of connections between sports and technology. This shift marks a noted development in student knowledge generation consistent with prior work on the use of wearables in STEM learning contexts (Ching & Hagood, 2019; Searle & Kafai, 2015). More impressive are the student knowledge reformulations represented in the diverse set of prototype ideas they created. While many of these ideas were extensions of the example wearables that students were exposed to during the week, students also demonstrated significant innovation in recognizing new categories of problems to address.

Vero's case study demonstrates another important extension on how students perceive computing. Vero had considerable prior experience programming but had not been exposed to ideas of physical computing where the actions of computer programs can persist on small devices and result in mechanical actions. The shift from computing on computers to computing on smaller devices was an important realization for Vero and her peers.

Complementing an expanded understanding of computing were indications of participant interest development that also appeared across the surveys, case study, and projects. The daily survey responses hinted at the vast majority of students learning something of interest across each day of the program. Further, students reported wanting to participate in Data in Motion activities in their schools. More pronounced was the overwhelming number (70%) of students indicating that they planned to continue working on their prototype idea.

This interest in continuing their prototypes, however, sits in contrast to the lack of change in students' overall interest in building or using technology, as recorded by the survey. In some sense, we interpret this lack of change in interest with technology as reflecting the limited amount of building that students did during the week. Much of their time was spent designing and tinkering. While some were able to prototype the functionality of their design idea with the GoGo Board, students did not leave the program having constructed a physical artifact. We suggest that interest in continuing their prototype ideas could be a manifestation of the possibilities students saw for experimenting with technology in environments such as Data in Motion, but that this interest is still very much in development.

Collectively, these results support the idea that students experienced an expanded understanding and interest in computing. Consistent with prior work on STEM activation and practice-linked learning environments, we find that this type of learning environment has the potential to both deeply engage students and expand their interest in technology.

Limitations and future considerations

As we reflect upon this work, there are a few limitations that are worth noting. Survey completion was voluntary. We asked youth to complete the surveys, but they could opt out. This was done to ensure that we honor student preferences. As a result, it is possible that our survey data could be subject to selection bias where students with particularly good or bad experiences within the program were more likely to complete the survey. However, with student participation typically around 27 respondents, this limitation may be inconsequential. Also, survey responses were anonymous and did not include any unique identifier. This limits our ability to make statements about how much each individual shifted in their perceptions or draw connections between what students created and how they responded to the end of day or pre- and post-surveys. This design does, however, fit our guiding question around the overall utility of the sports-computing space as useful in authentically engaging learners.

Due to the large range in ages, it is possible that some of the younger students perceived the surveys more as quizzes. This perception may have led them to want to answer the survey "correctly." This would bias results to being very positive. However, even if this is the case, there were noticeable differences in which questions showed significant changes from pre-survey to post-survey and across the different days of the program. At the very least then, those differences are notable in comparison to the responses with no pre- to post-survey changes. Importantly, most of these limitations are with regard to the survey administration and have no impact on the qualitative findings, which are a focal point of the analysis. Additionally, we only highlight one students' experience of the Data in Motion camp. In future work, we intend to look closely at more individual student experiences over time.

There is a particular tension that exists when providing students temporary access to technology that is otherwise unaffordable to them. In the case of this project, students used Google Wear OS smart watches that each cost approximately 200. USD Many students were enamored and excited to use the watches, even if only for a short period of time. However, there were an equal number of students who expressed disappointment. None of the students in the camp wore watches, so the idea of a smart watch was, in some sense, a luxury. Not surprisingly, some students were saddened about not being able to keep it and were reluctant when it was time to share the watch with someone else. Others expressed hesitation in using many of the wearables for fear that they would break them. To address this, we have begun investigating low-cost solutions that students would be able to keep.

Developing low-cost alternatives that students can take with them also addresses a concern about students being able to continue their projects. Nearly 70% of students indicated that they wanted to continue working on their projects. However, it is not likely that the students owned the technological tools needed to complete their projects. At present, most of the available programmable smart watches require programmers to have reasonable proficiency in Java. In order to grow learning opportunities at the intersection of sports, computing, and wearables, there needs to be hardware and software in place that will make programming such devices tractable for young kids. Again, we would like to work towards a model where the equipment is sufficiently inexpensive and accessible, so it becomes more feasible for students to keep the technology. Another option that we are considering is partnering with local libraries or makerspaces, so students check out certain fabrication tools. While this does not address the challenge of students being able to own the materials, it does provide means for increased longevity of the project.

Finally, as it relates to future consideration, we are exploring opportunities to embed Data in Motion in physical education courses for K-12 students. Feedback from participants on perceptions of learning and their interest in completing Data in Motion activities in schools, points to a potential opportunity to incorporate computational thinking into physical education. Historically, computational thinking and computer science are taught in mathematics, science, and, occasionally, media arts courses. However, this reinforces a fairly narrow perspective of computational thinking. Engaging learners in computational activities in in-school physical education would help disrupt this. This has the benefit of garnering increased exposure for both children and teachers and may, in particular, attract students who traditionally identify as athletes into some computer science spaces.

Conclusion

Data in Motion provided a space for youth to generate connections between computing and sports. We see several important implications for designing computer science learning environments that derive from this work. Most broadly, the findings point to the intersection of sports, wearables, and computing as a generative space for engaging students in computational learning experiences. Here, we are thinking about Data in Motion as a collection of relationships, activities, and technologies that helped students explore and realize new opportunities. These experiences are important for thinking about broadening interest in computing. By reframing the ways that computing can align with athletics, we may be able to reach a broader population of youth. Overall, the survey responses, case study, and the descriptions of student project ideas paint a rich picture of students growing in their recognition that technology can have utility in athletics. We also build on the role of a social computing environment as central to this connection.

The projects that students developed took the principles that underlie some commercial wearables to foment a set of personally relevant projects. Additionally, while students were very much engaged in regular athletic activity, they saw the experiences in the camp as being worthwhile to pursue in school and of educational value. While perceptions of sports and technology were originally disjointed, students made stronger connections between the two over the course of a week. We also saw that focusing on sports as a context does not preclude engaged participation from individuals who do not self-identify as sports enthusiasts. Instead, the bi-directionality of the connection between sports and technology demonstrates that students can have meaningful experiences along a spectrum of prior interests in these two areas. If we imagine what an extended program might look like, we see room for increased discussion with youth around ethical use of technology and how their designed technologies might impact society. A STEM learning environment that demands epistemological pluralism is essential for comfort in learning and affords increased connections across domains.

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Appendices

Appendix A: Curriculum (Technology + Activities)

Technology

In addition to the standard set of sports equipment: soccer balls, basketball, hoola hoops, etc.; one of the unique opportunities provided by this experience was access to novel technologies. Several of these technologies are low cost versions of tools used by professional athletes and technology designers. Here we present the tools in the order that they were introduced to the participants.

Ultra-wide band indoor location tracking – Pozyx ultra-wide band transceivers were used to provide real time indoor location tracking. Four ultra-wide band anchors were positioned around a basketball court. Each anchor is at a known distance from the other anchors. Participants wear an ultra-wide band transceiver that is connected to a USB battery pack and secured with a fanny pack or elastic armband (Figure A1). Using a custom python script, relative position on the basketball court is displayed on a central computer and recorded to a database. The custom script also keeps track of the total distance a participant has moved, and their maximum velocity.

Play Impossible Game Ball – this commercially available ball (Figure A2) includes sensors that track various aspects of the ball's motion. For example, participants can see how much force they applied to the ball, how fast they threw it, how high or far it traveled, and how fast it is spinning. Data is transmitted in real-time via Bluetooth to an iPad, Android, or Windows aThese different values are used in conjunction with individual or multi-person challenges.

Sensor Playground – the research team developed an application that allows students to explore some of the sensors available on the Mobvoi E2 TicWatch. Upon launching the application, users can select to test the accelerometer, gyroscope, step detector and heart rate sensor (see Figure 3). Within the accelerometer and gyroscope modes, participants can select which axes they want to be active. Once they have selected the axes of choice, they are taken to a screen that displays the corresponding sensor data in real-time, and the maximum value that has been reached during the session. There is a reset button that starts a new session. Finally, the application is configured to

Figure A1. Pozyx anchor (top), Pozyx tag (right) and USB battery pack (left).

Figure A2. two play impossible game balls with charger.

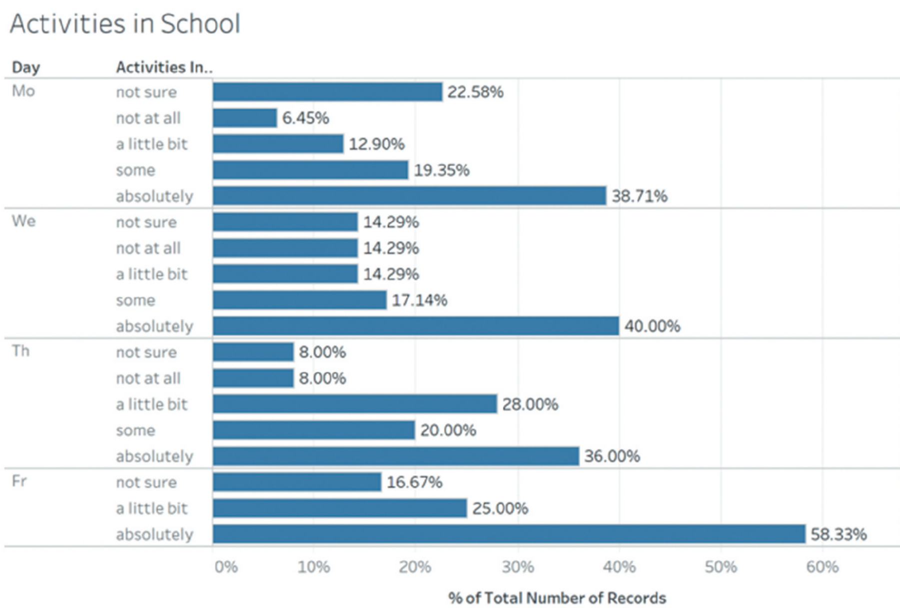

Figure 3. Student responses about doing data in motion in schools.

Figure A3. Sensor playground app home screen.

make the watch to vibrate for 2–4 seconds when students exceed 20 m/s2 in acceleration or angular velocity. The step counter mode shows how many steps have been taken in a given session, and the users current heart rate.

Tap the Flag – the research team also developed a Wear OS application that makes use of the Estimote beacon proximity API. The Estimote API allows the watch to measure how far it is from a particular beacon. When the application launches, players select their team in correspondence with the color of their Estimote beacon. Once they have selected their team, the application displays the score for each team. When a player taps, or gets sufficiently close to the target Estimote, the watch vibrates. Figure 4 features a picture of the Tap the Flag landing page.

GogoBoard – the GogoBoard [18] (see Figure A5) is a low cost microcontroller that was specifically designed for education. It has easy connectors for its eight sensor ports and four actuators ports. A built-in display allows students to see different sensor values in real-time, even when the board is not connected to a computer. When the board is connected to a computer, students can use a block-based programming environment to write programs to the board.

Figure A4. Tap the flag app home screen.

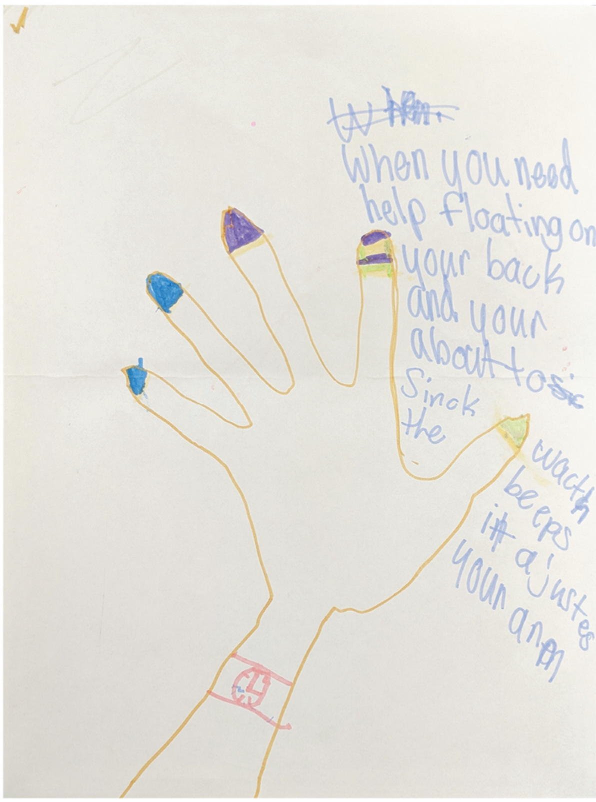

Figure 4. Action automation wearable for backstroke. "When you need help floating on your back and your about to sinck the watch beep it ajustes your arm".

*Spalding Smart Sho*t – this wearable was made for the purpose of indicating proper arm position to shot a basketball. This armband, worn on the forearm of the shooting arm, contains a speaker, LED, battery, and accelerometers to detect the orientation of the arm. When the device is at the right angle, it will light up and buzz.

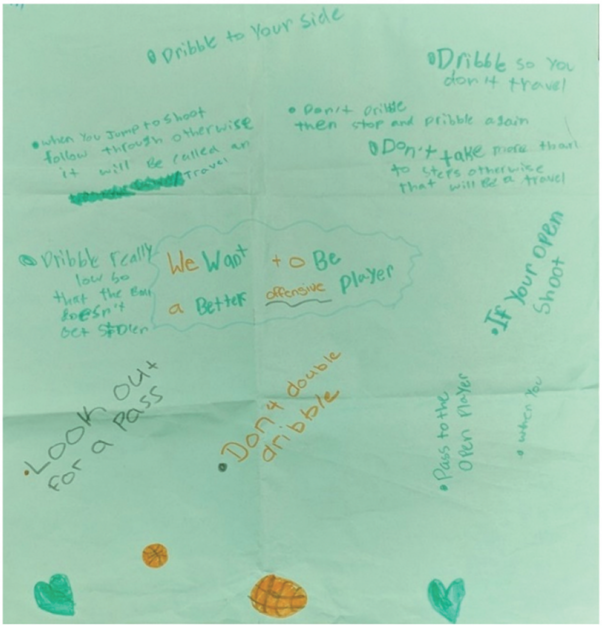

Figure 5. Ideation process for skills to improve with Basketball wearable device: Including "Dribble to your side," "Dribble really low," "If your open shoot".

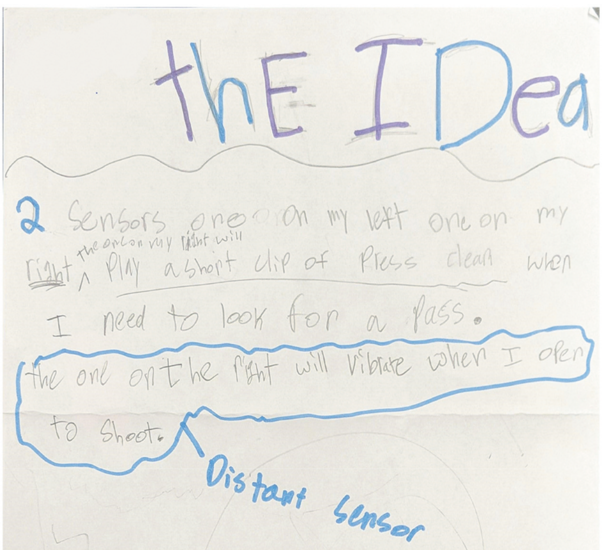

Figure 6. Description of basketball wearable device: "Sensors one on my left one on my right. The one on my right will play a short clip of press clean when I need to look for a pass. The one on the right will right will vibrate when I open to shoot (distant sensor)".

Android Smart Shot – the research team developed an application that replicates the functionality of the Spalding Smart Shot on an Android smartphone. Much like the sensor playground, the

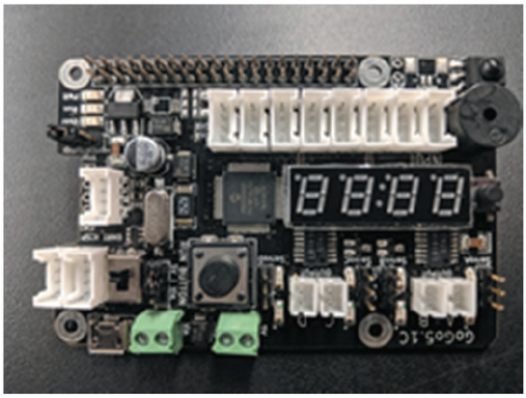

Figure A5. GogoBoard microcontroller.

application displays accelerometer data in real-time, and provides the user with feedback when certain accelerometer values are reached. When the phone is within a set range of accelerometer values, the screen background turns red. Once the values leave that range, the screen background returns to being white. A primary reason for developing this application was to help students see the underlying logic of the Spalding Smart Shot. Additionally, because it was made in MIT App Inventor, it help validated the utility of block based programming to make 'real' applications, something that some students expressed doubts of.

Homecourt.AI – this application uses computer vision to track player position and ball position, of a single user on a basketball. It also includes some basketball drills, and will keep track of someone's shooting accuracy while they are practicing. The tool was introduced to the students to show them opportunities to make applications that do not require wearable sensors, but that can still track information about athletic performance.

Activities

Over the course of a week (five days), we held one-hour sessions in the mornings, and afternoons, which featured activities that each tied into the theme and goals of the day. The first two sessions focused on open and directed play that introduced students to the technologies and helped them begin formulating questions around how sensors work. The next two sessions shifted to activities that let the students breakdown and explore the inner workings of some of these technologies and to identify what role a sensor could play in different contexts. We also began working with the students to how the introduction of sensors could contribute to achieving their sports-related goal. During the last two sessions, the students applied what they had learned over the week to draft designs for wearables that would address their sports performance goals and prototype on the gogo-boards. During the final session, they also played Tap the Flag. Brief descriptions of each activity can be found below.

Playing with Wearables – Pozyx was introduced with 5-on-5 basketball. Each participant was fitted with an ultra-wide band transmitter, a battery pack, and an armband or fanny pack to secure the technology. As students played basketball, their indoor location data was displayed in real time.

Android Watch Sensor Challenge – using the Sensor Playground app, students were presented with a variety of challenges. For the accelerometer and gyroscope modes, students were asked to determine what kinds of movement would consistently make the watch vibrate along the different axes. For the step detector, students were challenged to consider how the step detector worked as instantiated through a two challenges: First, students were asked to increase their step count, on

Figure A6. Figure B6. Spalding Smart Shot

the watch, without actually taking steps. Second, they were asked to take as many steps as possible without having the step count increase.

XYZ Racing – this activity was designed to give students an introduction of the X,Y,Z 3D Cartesian coordinate system. We used the different directions from baseline to baseline and sideline to sideline to represent movement along the X and Y-axis respectively. The Z-axis was represented by movement up and down. To reinforce these ideas, XYZ racing culminated with the research team naming an X,Y, or Z axes and the participants moving in the appropriate direction as quickly as possible.

Drills with Wearables – students were asked to either dribble and shoot a basketball or pass a soccer ball while using their wearable. As they performed different actions, they received feedback from the android watch around the magnitude of their gyroscope or accelerometer data. One of the prompts that students completed was to compare their gyroscope and accelerometer data between their dominant and non-dominant hand or foot. Throughout the activity, students documented their data and reflected on ways to make sense of the data.

Impossible Game Ball Challenges – students participated in teams, or individually to complete one or more challenges. These team challenges included tossing the ball and catching with the lowest force, achieving the longest air time, and reaching the lowest spin while tossing the ball the highest.

Introduction to Physical Computing – Over the course of two sessions students were introduced to the GogoBoard. During the first session, students tested out a number of different sensors. During the second session on physical computing, students were taught to use actuators and block-based programming (GogoBoard Prototyping).

Wearable Deconstruction and Critique – in this activity, students tested, critiqued and deconstructed the Spalding Smart Shot. Students worked in groups to brainstorm how the device worked, provide a critique of its utility, and disassemble it.

Project Ideation – students worked individually or in groups to brainstorm athletic performance-related practices that they wanted to improve. Students began by setting goals for things to improve, and then considered the types of sensors and/or wearables that might work for their design idea. They also created sketches of their ideas.

Tap the Flag Game – To showcase a potential synthesis of sports and tech we designed a game that combines basketball, Estimote beacons, and Android smartwatches. Tap the Flag is a variation of Capture the Flag and 5-on-5 basketball, where players must now enter the opposing team's half through a combination of strategic dribbling and passing among teammates. They must tap the beacon with their smartwatch to score points. Each player receives a smartwatch which is configured for their respective team. An Estimote Bluetooth beacon is placed under each basketball hoop with a large hula-hoop around it to demarcate the "no defense zone."