Guest Editorial: Special Section on Learning through Wearable Technologies and the Internet of Things

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THE Internet of Things (IoT) is being touted as "the next technological revolution" and one that will be "the most potentially disruptive" we will see in our lifetime, surpassed only by the World Wide Web and universal mobile connectivity [1, p. 24]. It involves physical objects with embedded computational and networking capabilities communicating and interacting with one another, with other computing devices, as well as with users on the global Internet. With the advent and growth of the IoT, homes, workplaces, and educational institutions—even entire cities and countries—are becoming increasingly "smart" and interconnected, which promises to substantially enhance or change the ways in which we live, play, work, and learn.

Amid the rise of the IoT, we have also been witnessing advances in wearable computing and electronic technologies that have made possible the creation of the "Internet of Me" [2]. Such technologies have now entered the mainstream [3] and products powered by them are becoming ever more readily available on the mass market, with consumer-level devices like smart glasses (e.g., Google Glass, Microsoft HoloLens), smart watches (e.g., Apple Watch), smart clothes, fitness bands/activity trackers (e.g., Fitbit, Nike+ FuelBand), and head-mounted cameras (e.g., GoPro) regularly dominating the technology news headlines of late. These technologies and devices along with others still under development are able to augment human cognition, behavior, and interactions in powerful ways that were previously inconceivable.

It is clear that wearable technologies and the IoT hold much potential for education and training [4], [5], [6]. Despite the considerable attention and interest they have garnered among educators [7], [8], [9], [10], however, there continues to be a dearth of real scholarship surrounding their use for learning and teaching, the majority of published work to date consisting largely of anecdotal reports or being primarily technical in nature. Little regard has been given to how the unique affordances of the technologies can be best exploited in concert with sound pedagogy and instructional design to facilitate the achievement of specific learning outcomes and goals. This special section of the *IEEE Transactions on Learning Technologies*, together with a special "sister" issue of the *IEEE Transactions on Education* (*ToE*) that is being published in parallel with it [11], seeks to begin to address the gaps in the scholarly knowledge base. The focus of the *ToE* issue is on pedagogical and curricular initiatives within the computer science and engineering disciplines that are aimed at encouraging students to learn both with as well as about wearable, IoT, and related technologies through a "maker" approach. In contrast, the present issue is concerned with the design, development, implementation, and evaluation of applications and interventions based on these technologies for assisting learning across a range of domains and disciplines.

This special section contains seven papers reporting innovations in six countries that represent the diverse domains of physics, public speaking, health and physical education, statistical literacy, language learning, and computing. In the first paper, which is entitled "gPhysics—Using Smart Glasses for Head-Centered, Context-Aware Learning in Physics Experiments," Jochen Kuhn, Paul Lukowicz, Michael Hirth, Andreas Poxrucker, Jens Weppner, and Junaid Younas of the University of Kaiserslautern, Germany describe their use of smart glasses to enhance high-school science experiments in the area of acoustics. The authors designed a Google Glass-based app for supporting inquiry-based learning by students as they explore the relationship between the frequency of the sound produced by striking a vessel of water and the amount of water in the vessel. The water fill level and sound frequency are automatically measured, and a dynamic graph of the two variables displayed via the smart glasses. Although between-groups comparisons showed no significant differences in terms of learning outcome attainment, they indicated that the wearable approach had a positive impact on students' sense of curiosity and wonder. The automated measurement and graphing capabilities of the app were also found to reduce cognitive load and time taken to complete the experiment, but those benefits were more pronounced with students using a tablet PC version of the app instead of the Google Glass version, which the authors attribute to the current limitations of the Google Glass device as well as students' relative lack of familiarity with the device.

Jan Schneider, Dirk Börner, Peter van Rosmalen, and Marcus Specht from the Open University of the Netherlands, in the second paper, "Can You Help Me with My Pitch? Studying a Tool for Real-Time Automated Feedback," report on their efforts to develop and test a system that utilizes a combination of wearable, voice-analysis,

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and motion-sensing technologies to provide learners with feedback as they practice delivering an oral presentation. Shortcomings and deficiencies in learners' non-verbal communication skills are diagnosed in real time, and visual and haptic cues are used to signal to them how to make improvements in aspects such as body posture, use of gestures, speech volume, and pauses. The system was trialed with adult participants who were tasked with giving an elevator pitch on a topic of their choosing. The results showed significant positive effects on learner motivation, confidence, self-awareness, and performance.

The next two papers in the special section relate to the use of wearable and IoT technologies as part of game-based learning approaches. The third paper, "Enhancing Physical Education with Exergames and Wearable Technology," by Renny Lindberg, Jungryul Seo, and Teemu Laine of Ajou University, South Korea, tells of how an exercise game or "exergame" adaptation of the popular strategy board game Othello (sometimes known as Reversi) was created, based on near-field communication tags and wearable sensors. The aims were to encourage physical activity among elementary-school students and to teach them content linked to the national physical education (PE) curriculum. Evaluation results point to increases in exercise efficiency, student motivation, and physical activity levels arising from participation in the exergame. Reflections and recommendations are offered pertaining to the use of wearables and wearable exergames for overcoming some of the challenges inherent in PE instruction.

The authors of the fourth paper, "Representing and Reconciling Personal Data and Experience in a Wearable Technology Gaming Project," Cynthia Carter Ching, Mary Stewart, Danielle Hagood, and Roxanne Rashedi of the University of California, Davis, USA, employed an online game as a means of encouraging middle-school students to critically engage with and make sense of their physical activity data. Their ethnographic study used grounded-theory analysis to understand how the students negotiated conflicts between their data as manifested in the game on one hand and their real-life embodied experiences on the other, yielding insight into the learning that transpired from the process. Ching et al. conclude with a discussion of the practical implications of their findings, including the potential for leveraging the affordances of physical activity monitors and other technologies of the Quantified Self (QS) movement in ways that move beyond persuasion and reward to intrinsically motivate and engage learners.

The fifth paper, "Appropriating Quantified Self Technologies to Support Elementary Statistical Teaching and Learning," presents an alternative application of QS technologies for learning and teaching. Victor Lee, Joel Drake, and Jeffrey Thayne of Utah State University, USA report on a mixed-methods study in which 5th-grade students wore Fitbit activity trackers to generate data that they used to collaboratively explore basic statistical concepts. The results provide convincing evidence of learning gains and advantages over conventional instructional methods, with improvements being demonstrated on statistical thinking constructs in areas such as data display, modeling variability, and informal inference. In their paper, the authors also highlight a number of technical and design considerations involved in adapting and implementing the necessary hardware and software components to overcome problems and barriers that exist.

In the sixth paper, "Introducing IoT and Wearable Technologies into Task-Based Language Learning for Young Children," Elena de la Guía, Vicente López Camacho, Luis Orozco-Barbosa, Víctor Brea Luján, Víctor Penichet, and María Lozano Pérez of the University of Castilla-La Mancha, Spain showcase their use of IoT and wearable technologies in the English-as-a-Foreign-Language classroom. Elementary-school-aged children participated in a task-based scenario requiring them to role play the preparation of a meal, including shopping for ingredients and using them to "make" several dishes. This entailed conversing in the target language as they enacted various steps involving sensor-based objects representing food items and kitchen utensils as well as wearable devices displaying status messages and feedback. The system and learning task design along with the evaluation results presented by de la Guía et al. offer proof of concept that the approach can be successfully used to motivate students, scaffold their activity, foster collaboration among them, and assist them in internalizing newly encountered vocabulary. It can also simplify the gathering of assessment evidence for diagnostic and reporting purposes, freeing up teachers to focus their attention on cultivating a classroom environment that is most optimal and conducive to learning.

The seventh and final paper in the special section, "Knowledge Construction in Computer Science and Engineering when Learning through Making," by Patricia Charlton and Katerina Avramides of the Institute of Education at University College London, U.K., gives an account of a pilot study that investigated the use of tangible toolkits for physical computing to support pedagogies of collaboration and production in STEM (Science, Technology, Engineering, and Mathematics), with a particular emphasis on computer science and engineering. The design-based research inquiry saw Year 10 students partaking in multidisciplinary, problem-based learning to design and prototype various smart-city projects. The findings shed light on the knowledge-construction processes that occur when students learn through making in complex environments, and have also been used by the authors to inform the design of effective data analytics and visualization tools as part of a wider project aimed at advancing practice-based experiential learning in STEM.

While not necessarily fulfilling techno-utopian visions of the future perpetuated by the media, innovations such as those featured in this special section bring us a step closer toward achieving seamless integration and interweaving of digital technologies into everyday life—a longstanding goal congruent with the desire of educators to create ubiquitous learning opportunities, and one that presents countless possibilities for authentic learning linked to or tied in with learners' day-to-day activities [12], [13], [14], [15]. As wearable and IoT technologies increasingly enable learner interactions and experiences to straddle the digital and physical realms, we may start to see a gradual fading of the modal distinctions and labels that are so often used to characterize technology-enhanced learning, eventually relegating such prefixes as "e-" (for "electronic") and "m-" (for "mobile") to things of the past, and rightfully returning the spotlight to the learning itself. Concomitant with this, there is much promise for addressing the long-neglected kinesthetic aspects of learning, and for bridging the divide between formal, informal, and non-formal learning. It is hoped that the papers in this special section will contribute to the building of a rigorous evidence base that will guide and support practice surrounding the use of wearable and IoT technologies for learning, as well as inspire and inform ongoing research and development in this rapidly emerging and evolving space.

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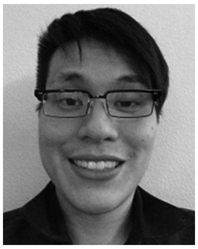

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