Examining the Use of Wearable Technologies in K-12 Education: A Systematic Review of the Literature

by

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The project was approved on 12 April 2020 by the following review committee:

Review Committee:

Research Supervisor	Dr. Robin Kay
Second Reader	Dr. Janette Hughes

The above review committee determined that the project is acceptable in form and content and that a satisfactory knowledge of the field was covered by the work submitted. A copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

This paper seeks to uncover how wearable technologies are used in K-12 education contexts. A systematic review of the literature was conducted using the PRISMA framework in conjunction with a thematic narrative analysis. A total of 52 peer-reviewed articles from 2003 to 2019 were examined. Five key categories were identified to organize empirical and narrative data considered from both the perspective of teachers and students. The categories include pedagogical uses of wearable technologies, benefits of using wearable technologies, challenges of using wearable technologies, attitudes toward the use of wearable technologies, and practical issues with the use of wearable technologies.

Keywords: systematic review; wearable technology; learning; K-12 education

AUTHOR'S DECLARATION

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Philip C. Jovanovic

DEDICATION

With all my heart, I dedicate this project to my wife, who gracefully navigated me over treacherous pitfalls on a journey I can't imagine without her.

I also dedicate this project to the warmth and unconditional support of my loving family.

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LIST OF ABBREVIATIONS AND SYMBOLS

BVP	Blood Volume Pulse
CRD	Centre for Reviews and Dissemination
ECG	Electrocardiography
EDA	Electrodermal Activity
EFL	English as a Foreign Language
GPS	Global Positioning System
K-12	Kindergarten to Grade 12
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RFID	Radio-Frequency Identification
RSP	Respiration
SKT	Skin Temperature

1. Introduction

1.1 Overview

The inclusion of miniaturized sensors for physiological measurements into discreet mobile devices is a common aspect of everyday wearable technologies. However, the literature on wearable technologies suffers from inconsistent terminology and definitions. Therefore, for this review, I proposed a new definition of wearable technologies synthesized from the existing literature (see Table 1). Wearable technologies are operationally defined as web-connected, sensor-embedded devices designed to be worn on the body and record neurophysiological or physical data to augment self-management and mediate a more knowable self in dynamic contexts

As these wearable, sensor-rich devices are becoming more ubiquitous and affordable, teachers and students are adopting this technology for constructivist-based learning. Constructivist-based learning expands on what Jones et al. (2003) called *production pedagogies* or ways to learn through developing educational materials or objects. With a growing body of young explorers probing the functions of evolving digital devices, a culture of children as producers, or *digital makers* is emerging (Kim & Searle, 2017). This new generation of digital makers is at the cusp of exposing new ways to learn through wearable devices, and recent research supports the use of wearable technologies to help create engaging and personalized learning experiences for children (Borthwick et al., 2015; Grawemeyer et al., 2017; Kim & Searle, 2017; Siering et al., 2019; Zhang et al., 2018).

The modest size and versatility of wearable devices provide multiple avenues of exploration and experimentation within academic settings and versatility of where and how these devices are worn. Some devices can be worn externally around a limb, clip onto clothing, or even stick to the skin as transferable tattoos. Compared to obtrusive, traditional methods of attaching sensors to headbands or large helmets, the latest range of wearable sensor-embedded devices are unobtrusive and discreet.

Flexibility in the design and application of wearable technologies has led to new research initiatives in education. A variety of studies have focused on smartwatches used as activity trackers in physical and health education (Casey et al., 2017; Lee et al., 2015; Lindberg et al., 2016; Mosier, 2014), language learning (Shadiev et al., 2018), cross-curricular studies (Engen et al., 2018), or as emotion-based learning tools (Lupton & Williamson, 2017). Other wearables such as miniaturized clip-on cameras have been used for real-time noticing in pre-service teacher training (Estapa & Amador, 2016), or the use of radio-frequency identification (RFID) badges for the administration and security of student bodies (Borthwick et al., 2015; Mastrandrea et al., 2015), and in gamified learning (Bower & Sturman, 2015; Gilmore, 2015; Siering et al., 2019). There is also an emerging use of wearables in the form of student manufactured smart textiles in makerspaces (Hughes & Morrison, 2018).

However, to date, a comprehensive systematic review of the research on the use of wearable technologies in K-12 environments has not been conducted. The purpose of this paper was to review the literature on the use of wearable technologies for teaching and learning in K-12 contexts and to understand the multiple factors and perspectives that influence the real-world application of the technology. To achieve the purpose of this paper, I examined pedagogical uses of wearable devices, the benefits and challenges of using wearable devices for teachers and students, attitudes of teachers and students toward wearables, and the practical issues that affect the use of wearable technologies for teaching and learning.

1.2 Definitions

1.2.1 Wearable Devices

According to my review of the literature, there is no single, consistent definition of wearable devices. For example, some authors note a trend to modernize *wearable computers* to the more flexible term *wearable technologies* (Bower & Sturman, 2015). Other terms used in the literature include *activity tracking devices* (Mosier, 2014), *wearable computers* (Labus et al., 2015), *everywear* (Gilmore, 2015), *e-textiles* (Kim & Searle, 2017), and *smart wearables* (Egger et al., 2019). The variety of sensors, where and how they are worn, and the unique settings lead to inconsistent definitions of wearable technologies. For example, in contexts that use smart textiles or e-textiles, wearable sensors are embedded in clothing items that take on many diverse shapes and forms (Cherenack & Van Pieterson, 2012; Hughes & Morrison, 2018; Kim & Searle, 2017). Defining wearable technology is further complicated by the speed at which commercial wearable devices evolve in size, shape, and functionality. Table 1 provides a summary of definitions for wearable technology identified in this literature review.

Table 1

Definitions of Wearable Technologies in the Literature

Definition	Source
Activity tracking devices that can "measure distance, movement, energy expenditure, speed, nutrition habits, sleep patterns, mood levels, and other variables" (p.46)	Mosier (2014)
A wearable computing paradigm is one that requires (a) constant connection to the wearable computer, (b) augmentation of senses, and (c) mediation with physical reality.	Labus et al. (2015)
Wearable digital devices "incorporate wireless connectivity for the purposes of seamlessly accessing, interacting with and exchanging contextually relevant information." (p.344)	Bower and Sturman (2015)
Everywear are "technologies that are designed in some way to make the body and its movements more knowable and, through this knowability, to promote healthy lifestyles and habits, particularly among at-risk persons." (p.2528)	Gilmore (2015)
Wearable technologies are "bio-sensing devices, usually taking the form of a wristband, a chest band, or a headband, and capable of recording human neurophysiological signals without interrupting the performance." (p.1)	Zhang et al. (2018)
Wearable devices are "unobtrusive and hyper-personal because they also can measure vital statistics, such as health data." (p.323)	Engen et al. (2018)
Wearable devices support self-management, "for example, fitness trackers or smartwatches that were developed to provide support in increasing physical activity." (p.1)	Siering et al. (2019)
"Smart wearables provide contact with the skin and physiological parameters such as electro-dermal activity and heart-related signals can be recorded unobtrusively during dynamical tasks." (p.1)	Egger et al. (2019)

1.2.2 Sensor Types

The range of sensor types embedded in wearable technologies influence design and application. Teachers should have a working knowledge of the sensors to inform pedagogy and design curriculum involving wearable technologies. Some sensors are simple and measure location, body acceleration, and heart rate, where more advanced sensors detect electrical signals in the skin, heart rate, perspiration, and brainwaves. See Appendix A for a detailed description of key sensors available in wearable devices.

1.3 Research Questions

I developed five research questions to explore the experiences and perceptions of K-12 teachers and students on using wearable technology for teaching and learning. These questions were

1. How are wearable technologies used in K-12 contexts?
2. What are the benefits of using wearable technologies in K-12 contexts for teachers and students?
3. What are the challenges of using wearable technologies in K-12 contexts for teachers and students?
4. What attitudes do teachers and students have regarding the use of wearable technologies in K-12 contexts?
5. What are the practical issues that affect the use of wearable technologies for teaching and learning in K-12 contexts that are not specific to students or teachers?

2. Method

2.1 Overview

In this paper, I used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Liberati et al., 2009) to explore the literature on teaching and learning with wearable technologies for Kindergarten to Grade 12 (K-12). PRISMA offers a robust foundational structure for researchers to conduct reliable treatments of existing literature, emphasizing reliability, transparency, and clarity. No existing or registered review protocol informed the methods of this study. Therefore, I used the screening and analysis procedures outlined by the Centre for Reviews and Dissemination (CRD) (2009).

2.2 Eligibility Criteria

The eligibility criteria for selecting articles targeted empirical research and positional academic investigations that revealed critical insights about wearable technologies and/or sensors applicable to K-12 settings. These insights included themes involving learning, teaching, attitudes, feasibility and security. Overall, *wearable(s)* was the dominant keyword criterion for this study, supported by a reference to *digital technology* (including popularly named or trademarked technology), the term t*echnology* alone, or *sensors*. The setting of this review focused on the use of wearable technologies and sensors in the domain of K-12 schools with a specific emphasis on the perspectives of teachers and students. Eligible articles fit a publication range between 2003 to 2019. All articles satisfied the academic, peer-review criterion. No restrictions on language or country of origin impacted eligibility. Furthermore, any articles included outside of the K-12 setting and acceptable date range were used to record key definitions or for a foundational understanding of relevant technologies under review. My rationale for the selection criteria was to obtain a broad, holistic body of literature, representing an orchestration of teacher and student voices in the K-12 context.

2.3 Information Sources

I initially used six information databases for this project. The primary database used was the Ontario Tech University Online Library Database powered by Summons Service. I then used five additional databases through iterative searches, as recommended by the education librarian at Ontario Tech University. The databases include ERIC via EBSCOhost, Education Source via EBSCOhost, IEEE Xplore, LearnTechLib, and Google Scholar. Finally, an important tertiary information source included records gleaned from reference lists of articles selected at different stages of the article screening process.

2.4 Search Strategy

The Ontario Tech University Online Library Database provided an initial test ground for an iterative series of probing searches as recommended by CRD (2009, p.48). The test phrase *wearable technologies for education* exposed the need for fewer, specific search terms using Boolean operators (e.g., AND, OR, NOT). The final search term, *wearables AND education,* was entered into the Ontario Tech University Library Database. Filters applied to the search ensured that the results were scholarly, peer-reviewed journal articles from the education discipline, with *children* as the subject term. Ninety-nine relevant results were revealed and investigated further. After scanning titles and abstracts, I added the search term *sensor*s. With three key search terms available, I expanded the full search to five target databases: ERIC via EBSCOhost, Education Source via EBSCOhost, IEEE Xplore, LearnTechLib, and Google Scholar. Finally, I scanned the reference and literature review sections of articles selected for full-text review to find any additional relevant articles.

2.5 Data Management

I used a spreadsheet to create an inventory of article characteristics and in-text themes. For efficient sorting, grouping, and summarizing, the final article characteristics included: authors and year, population, sample size, sample description, reliability, validity, subject area, study type, behaviour, attitudes, learning, and feasibility. I created a second sheet to record emergent themes gleaned from a deep reading of individual articles and then a final sheet visualizing the thematic framework.

2.6 Article Selection

With an emphasis on discovering insights into wearable technologies and sensors, target vocabulary (e.g., learning, teaching, attitudes, feasibility and security) helped pre-focus article selection. I screened titles and abstracts of potential articles for inclusion, discarding articles outside the realm of K-12 education. Unclear statements about population within titles and abstracts warranted a secondary screening. I achieved the definitive assessment for inclusion criteria in the secondary screening phase via retrieval and review of full-text digital articles.

2.7 Data Analysis and Coding

Narrative depth is the focus of data analysis in this review. A large number of articles under review reported empirical evidence, whereas other articles enriched the data set with a wide-scope of positional narratives. Therefore, I treated empirical data and narrative data inclusively. I used a thematic narrative analysis approach with inductive, data-driven coding to increase the voices or perspectives previously silent in the data and blend the data (Boyatzis, 1998). The in-text narrative analysis helped to extract a deep thematic structure through the identification and summarization of key article highlights.

I identified and summarized critical highlights on a spreadsheet. Note that multiple highlights emerged from each article. After a highlight was summarized, it was assigned a main category based on the proposed research questions for this review. The categories were:

1. Pedagogical uses of wearable technologies
2. Benefits of using wearable technologies
3. Challenges of using wearable technologies
4. Attitudes toward the use of wearable technologies
5. Practical issues with the use of wearable technologies

I then assigned a sub-category to each data point based on one of the 32 themes that emerged in the analysis (see Appendix B). Finally, I labelled data points according to whether they reflected a teacher or student perspective.

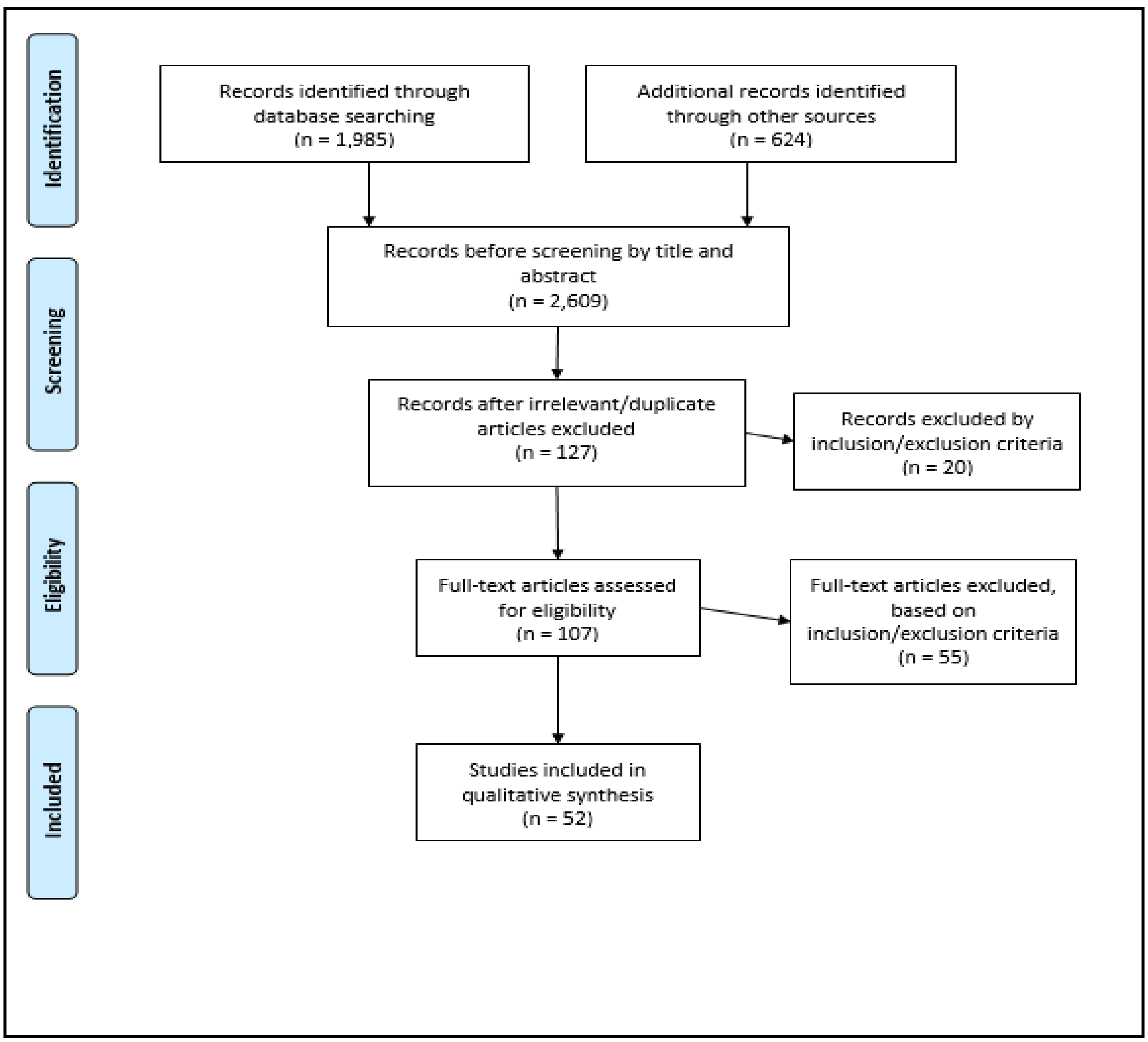
3. Results

3.1 Article Analysis

After applying the article selection strategies reported in the methods section, I identified 52 articles for inclusion in this review. The search of databases was conducted between June 2019 and August 2019. The steps applied in identifying articles, screening articles, determining eligibility and final inclusion of articles are outlined in Figure 1.

Figure 1

Study Selection Flowchart



Note. The study selection flowchart is adapted from "Preferred Reporting Items for Systematic Reviews and Meta Analyses: The PRISMA Statement," by A. Liberati et al., 2009, *Open Medicine 3*(3), p. 123-130. Copyright 2009 by the PRISMA Group.

3.2 Identification

I identified records into two different streams (see Figure 1). The first stream collated all records populated in academic databases, including the Ontario Tech University Online Library Database, ERIC via EBSCOhost, Education Source via EBSCOhost, IEEE Xplore, and LaernTechLib. The second stream combined results from Google Scholar and the snowball method of collecting articles from the reference sections of papers. Both streams combined to produce 2,609 records.

3.3 Screening, Eligibility, and Inclusion

I used the screening phase to first skim records by title, then by abstract, when titles were unclear or inconclusive. For example, if titles contained alternate phrasing of my keyword criterion, I read the abstract to determine if the record passed the initial screening criteria. Any records that did not contain at least one keyword criterion or referenced post-secondary or adult populations were removed. The initial screening produced 127 articles for full-text review. An additional 20 records were removed after a secondary screening of abstracts. Next, 107 articles were downloaded and stored for full-text analysis. Of these articles, 55 were excluded due to references to specific technologies that did not fit the criterion of *discreet wearable* (e.g., smartphones or tablet computers) or referenced devices particular to the medical field. Some exceptions were made at this stage to allow for the collection of articles that provided a foundational understanding of the field, provided definitions of sensors or wearable technologies, and that contributed to the qualitative narrative of my thematic analysis. A total of 52 articles were included in my final review.

3.4 Study Characteristics

For each study included in my final review, I extracted the following characteristics: authors and year, population, sample size, sample description, reliability, validity, subject area, study type, behaviour, attitudes, learning, and feasibility. Each study characteristic provided scaffolding for organizing and targeting my thematic narrative analysis and synthesis of non-empirical data. A *feasibility* characteristic was used to summarize each study as either "ready for use," "ready for use with challenges" or "not ready for use." A total of 32 studies reported empirical data through various experimental designs, and 20 articles provided either a direct reference to empirical studies or were entirely positional-narrative, non-empirical, or foundational works.

In terms of authorship, eight articles were written by or included the same author, and 48 articles did not include duplicate authorship. Article publications, by year, appear in Table 2.

Table 2

Distribution of Papers by Year

Year	2003	2004	2011	2012	2013	2014	2015	2016	2017	2018	2019
Papers	1	1	1	1	3	2	9	6	9	12	6

Thirty-two out of 52 articles reported described the study population. In terms of domain, articles focused on elementary school children (n= 9), middle school children (n=1), secondary school children (n=3), special education in the realm of Autism Spectrum Disorder (n=1), teachers or pre-service teachers (n=3), pre-school children (n=2), a combination of elementary, middle, and secondary school children (n=2), a combination of elementary and secondary school students (n=2), and mixed school age groups with teachers (n=9).

The feasibility outcome resulted in eight articles that provided evidence to suggest wearable technologies were ready for use in K-12 teaching and learning, 43 articles that offered balanced evidence for the feasibility of wearable technologies but with serious challenges, and one article that suggested wearable technologies were not ready for K-12 teaching and learning. A detailed description of my thematic narrative results is presented in the following section.

3.5 Key Themes

The narrative analysis of data from the 52 papers revealed five main categories and 32 themes. The five categories used to organize thematic data are (1) how wearable technology is used (i.e., pedagogical uses), (2) the benefits of using wearable technology, (3) the challenges of using wearable technologies, (4) attitudes toward using wearable technologies, and (5) practical issues. Teacher and student perspectives were used to further organize thematic data under categories two, three, and four only. Of the 32 themes used in the final review, some themes were repeated or grouped across the different categories. Appendix B lists the original theme in the first analysis, the main category, and the assigned subcategory.

3.6 How Wearable Technologies are Used (Pedagogical Uses)

The first research question was, “How are wearable technologies used in K-12 contexts?” Sixteen articles provided real-world examples of the technologies in use. These examples are organized under four themes: (1) student health and safety, (2) learning, (3) body movement and environment monitoring, and (4) the prediction of learning outcomes and diagnosing academic emotions.

3.6.1 Student Health and Safety

My review of the literature found four articles that provided real-world examples of how wearable technologies addressed student health and safety issues and teaching students to think about their own health.

The embedded sensors in wearable devices have allowed researchers to study environmental factors that impact the health of children. Research by Bagot et al. (2018) looked at how mobile sensors in wearable technologies can be used to measure the impact of air pollution on patterns of neurodevelopment, mental health, and prediction of health outcomes in children. Furthermore, the affordance of wearable devices to connect to the internet allows teachers in-charge of student safety to monitor students' locations remotely. For example, Jones et al. (2003) suggested that the combination of data from physiological sensors, and location data from miniaturized global positioning system (GPS) sensors in wearable devices, could be used to monitor the physical safety of children as they travel between home and school, or within schools.

Wearable technologies influence how students think about health education. Lindberg et al. (2016) reported increased rates of exercise and better engagement when students used wearable technologies in a game-based physical education learning context. Wearable device-based learning has even impacted health education on a global scale. Drew and Gore (2014) reported results from the Global Children's Challenge, that wearable devices encouraged the positive outcome of 165,000 children in 59 countries to take a total of 16,277 steps per day during the challenge.

3.6.2 Learning

I found eight articles in the literature that discuss how wearable technologies improve student learning. Different approaches to teaching and learning with wearable devices in this section include the neurophysiology of learning, blended medium learning (i.e., multimodal learning), constructivist learning, gamification, and simulation.

Zhang et al. (2018) suggested different emotional and cognitive learning strategies might be needed for different subject areas. Wearable devices in their study revealed different neurophysiological activity patterns of students between Chinese language classes and math classes. Teachers might be able to use student neurophysiological data collected from wearable devices to adjust methodological approaches to teaching between subject matter.

Additionally, Wargo (2018) found that students can benefit from learning enhanced with unique combinations of learning materials (i.e., multimodal learning), such as the *writing with wearables* activity in which students digitally recorded and annotated a creative story in real-time while moving through different indoor and outdoor spaces. The writing with wearables study demonstrated that unique conceptualizations of ways to learn inform how teachers plan lessons that blend different subject matter and learning technologies.

Wearable technologies can promote constructivist learning. Peppler and Glosson (2013) demonstrated that tinkering with wearable e-textiles can significantly impact the construction of circuitry knowledge. Additionally, Hughes and Morrison (2018) suggested constructionist learning can be realized through makerspaces as children create e-textiles that take the form of wearable technology for real-life applications and across learning contexts. As students experiment with different learning materials in makerspaces, they gain understanding through trial and error of how to construct their learning object, which embodies the fundamental aspects of constructivist learning. Jones et al. (2003) studied 10 to 12-year-olds' use of wearables to construct audio annotations of their surroundings or *soundscapes*. The students developed novel ways to use the different functions of wearables to create their soundscapes. The above examples point to the creative ways to implement the audio, visual, and manufacturing capacities of wearable technologies to enhance how students construct their knowledge and develop unique applications of the learning materials they use.

The final two approaches to teaching and learning with wearables found in the literature are gamification and simulation. The visual interface affordances of wearable technologies have been used to present learning as fun games or as realistic simulation exercises. Lindberg et al. (2016) found that students who engaged in game-based learning with wearable technologies demonstrated significantly better test scores when compared to students who learned via pencil and paper. Similarly, Konkel et al. (2004) found that wearables deliver meaningful, gamified learning scenarios that enhance engagement and help children to develop physical and cognitive skills simultaneously. Furthermore, wearables created learning experiences for students who would otherwise be disadvantaged by cost or distance. Bower and Sturman (2015) suggest that one of the critical affordances of learning with wearable devices is the ability to simulate realistic learning contexts and scenarios for students.

3.6.3 Body Movement and Environment Monitoring

Traditionally, teachers were limited to direct observations of students for insight on how the students interact in the learning environment, or how the learning environment affects the student. However, certain behaviours and interactions are difficult to observe without the help of the sensors embedded in wearable devices. Several studies examined how wearable technologies efficiently and accurately map the body movement of students across learning contexts to inform teachers about environmental effects on student learning. For example, Bagot et al. (2018) mapped the movements of students through learning activity spaces, including the length of engagement, as a way for teachers to better understand how children used the classroom spaces. Research into activity space data could help teachers design better learning spaces and help improve student engagement in classroom activities (Irvin et al., 2017).

Wearable technology has also been employed to analyze the impact of environmental visual stimuli on student learning. Signal et al. (2017) completed an in-depth analysis of food advertisements that Australian children were exposed to and influenced by daily. The study reported data from 1.3 million images recorded with wearable cameras during school hours and outside of school hours. The study illustrated how wearable devices collect and analyze information that influences student learning and health in various casual or formal contexts.

3.6.4 Prediction of Learning Outcomes and Diagnosing Academic Emotions

Wearable technologies also collect neurophysiological data associated with student performance to help teachers more accurately assess student learning outcomes. For example, Zhang et al. (2018) reported that neurophysiological data collected with wearable devices accounted for results of test scores that could not be explained by self-reported student data alone. Furthermore, the prediction of learning outcomes through neurophysiological data collected via wearables aids early diagnosis, classification, treatment, and monitoring of learning difficulties students may have (Morris & Sah, 2016; Selwyn, 2015).

Mehmood and Lee (2017) determined that the synthesis of data from different sensors embedded in wearable devices (i.e., multimodal data) can accurately and reliably identify at least four emotional states (sad, scared, happy, and calm) and other emotions that are important for student learning, also known as *academic emotions*. Additionally, Bach et al. (2013) reported data about reading skills and determined through a longitudinal study of 19 K-12 students that multimodal data collected with wearable technology accurately predicted the future reading skills of the students.

3.7 Benefits of Using Wearable Technology for Teachers

Wearable technologies can provide teachers with a range of benefits to improve their pedagogical thinking, understand the reasons some lesson designs succeed and others do not, better engage students in learning, and enhance their professional development. My review of the literature resulted in sixteen articles that address how teachers benefit from the use of wearable technologies in K-12 contexts. I found four thematic benefits: design benefits, data analysis and efficiency benefits, engagement benefits, and benefits for professional development.

3.7.1 Design

Nine articles referenced the three types of design benefits for wearable technologies as learning tools, including pedagogical benefits (i.e., applied design for learning), the physical form of the wearable devices, and the digital functions of the devices.

Table 3 lists 15 pedagogical benefits of using wearable technologies. Each benefit offers valuable insights that can impact how teachers think about, develop and design new learning environments and activities with wearable technologies in K-12 contexts.

Table 3

Applied Pedagogical Benefits of Wearable Technologies

Author	Benefit
Dahlstrom-Hakki et al. (2019)	1. Better testing and assessment of cognitively diverse students. 2. Better objective measure of a holistic view of the entire learning process, not just learning outcomes. 3. Better capture of implicit learning, which is traditionally difficult. 4. Application of real-time interventions based on real-time measures. 5. Less biased measure of long-term memory retrieval over summative assessments. 6. Better understand the impact of learning format and learning goals on student cognitive load.
Kim and Searle (2017)	7. Better learning experiences can be designed by understanding how children interact with learning devices in natural settings.
Kwasnicka and Naughton (2019)	8. Better ability for researchers to conduct longitudinal N-of-1 studies to analyze the trajectories of an individual's behaviours.
Labus et al. (2015)	9. Efficiency of e-education model benefits from capitalizing on cloud computing, wearables, and software. 10. Capacity to share context-aware, personalized, efficient, and relevant information to learners.
Lupton and Williamson (2017)	11. Increased capacity to detect affective, non-cognitive learning.
Merkouris et al. (2017)	12. Tangible computers offer better relevance, engagement, realism, communication, and collaboration.
Egger et al. (2019)	13. Affective computing and emotion recognition can help psychologists detect emotions in patients who have difficulty expressing emotion. 14. Wearable sensors are best suited to detect emotions as emotions are expressed over various pathways of human expression, which embedded sensors can accurately detect. 15. Multimodal sensor data from wearable technologies are better at detecting two dimensions of human emotion (valence and arousal) and can help conclude emotional state.

Second, the size and shape of the actual wearable devices, as well as standard device functionality, also offer attractive benefits to teachers. For example, Bagot et al. (2018) found two essential design aspects of wearable devices that can benefit teachers: non-invasive device design and objective, precision testing of causal models and hypotheses. In other words, wearable devices can provide discreet ways for teachers to collect accurate data on student activity and reflect on the meaning of the results in light of pedagogical theory. Additionally, Shadiev et al. (2018) identified eight beneficial functionality design factors of smart wearables for learning: hands-free access, translation, speech-to-text recognition, pop-up notifications, voice recording, information sharing, ease of communication, and fitness tracking.

The inventory of design benefits outlined above can provide teachers with a resource to better understand some of the critical affordances that are inherent to wearable devices, and can also impact the real-world application of their pedagogical knowledge.

3.7.2 Data Analysis and Efficiency

To better understand education and learning as a whole, wearable technologies provide teachers with a way to analyze student data and data from different learning contexts efficiently. Williamson (2017) argues that the analysis of body data from students (i.e., psycho-informatics) is a viable approach to help teachers understand education and learning as a whole. Teachers may use psycho-informatic data to determine how well a student is learning and identify difficulties between academic subject matter. Similarly, Casey et al. (2017) emphasized the importance of data analyzed from wearable devices to help educators gain a clear image of how and where learning, teaching, and environmental context intersect. It is also essential that data analysis occurs efficiently. Bower and Sturman (2015) noted that a key benefit of wearable devices is the potential to speed up access to information, which may improve the delivery of learning materials and participation in learning.

3.7.3 Engagement

I found five studies in my review that inform teachers on how wearable technologies can enhance engagement in learning activities. One important affordance of wearable technology for teachers is the extension and continuation of student learning outside of the traditional classroom walls. Kim and Searle (2017) demonstrated that extending the use of wearables from the classroom into the home provided teachers with the ability to observe engagement of learning activities beyond the classroom, and better judge the usefulness of learning activities over time and across learning contexts. Shadiev et al. (2018) reported three uses of wearable technologies that help promote student engagement: increasing ability to complete learning tasks, allowing students to monitor their physical activity, and enhancing student-to-student communication.

Jones et al. (2003) suggested that wearable technologies help create learning contexts that allow children to feel free, safe, and adventurous, which improves overall engagement and exploration in learning. Furthermore, Liang et al. (2019) added that the affordances of smart wearable technologies, smartphone applications, and cloud-based computing could combine to create more engaging learning experiences for students, better pedagogical flexibility for teachers, and accurate prediction of learning outcomes across learning spaces.

Another example of how wearable technologies can be applied to enhance engagement is through the targeted use of emotion in learning (i.e., affective learning). Grawemeyer et al. (2017) used affective-based feedback delivered via wearable devices to improve student engagement by addressing student emotional states, such as frustration or boredom. Further research is needed to investigate the connection between wearable technologies, engagement, and affective-based learning.

3.7.4 Professional Development

Wearable technologies can offer in-service teachers and preservice teachers support for professional development. Wearables provide the affordance of making teacher professional learning live and in-the-moment and can improve insight for teachers into their teaching strategies (Estapa & Amador, 2016). Specifically, Estapa and Amador reported that in-the-moment learning helped preservice teachers become more aware of their delivery of information in the classroom. Providing a tool to help teachers improve awareness of their teaching strategies in different contexts, and in real-time, is a valuable benefit of wearable technologies. More research is required to determine different ways that wearable technologies can be used to enhance professional development.

3.8 Benefits of Using Wearable Technology for Students

I extracted eight themes from 16 articles regarding the direct benefits of wearable devices to students, including voice, ownership and self-reflection, relevance, accuracy and efficiency, learning, engagement, presence and space, physical needs, data analysis, and student profiles.

3.8.1 Voice, Ownership, and Self-Reflection

This section uses three themes, voice, ownership, and self-reflection to analyze how students engage with the data they create from their use of wearable devices. First, voice refers to student control over the data collected from their bodies and the synthesis and interpretation of this data. The interplay between student voice and wearable technologies, and the potential of the technology to improve learning, is illustrated well by Kim and Searle (2017) who note,

> New digital technologies can amplify student voice to provide learning experiences relevant to students' lives, especially for culturally and linguistically diverse students. This vision might be the ultimate expression of student voice offered by digital technology: enabling youth to be digital makers and thereby managers of their digital worlds and also blurring boundaries between students' voices and the digital tools with which they engage. (p.10)

The convergence of more enabled and engaged students in more relevant learning experiences points to the potential of wearables to improve K-12 learning experiences. Furthermore, Lupton and Williamson (2017) added that the summary and analysis of one's self through body data (i.e., datafication) could be enjoyable for children, especially if they are self-motivated and voluntarily create the data.

Second, in terms of ownership, students can take literal ownership over their data, but another form of ownership defines how students take control of the way they engage in learning contexts. Students can benefit from taking greater ownership over how they learn through the affordances of wearables, such as the ability to record personally meaningful audio and visual material while learning, communicate with other students in real-time about their learning goals, and leave electronic annotations on digital maps of physical spaces about their learning experience (Jones et al., 2003). Additionally, Merkouris et al. (2017) suggested that because students construct their knowledge through their use of wearables, they also gain a more profound sense of ownership over the overall learning process and their outcomes.

Third, for children to achieve voice and ownership in their data, it is important to encourage self-reflection. Lee et al. (2015) outlined three benefits to student learning when self-reflection is used to look at wearable sensor data: (1) students learn to interpret their data in meaningful and unique ways, (2) students learn how to design educational activities for self-improvement, and (3) students learn to predict their academic outcomes as they have a clearer understanding of their abilities. A key benefit to students of learning with wearables is to become more self-reflective about the data they create, how the data is produced, and what the data means.

3.8.2 Relevance, Accuracy and Efficiency

I found three articles in my review that include the themes of relevance, accuracy, and efficiency as crucial benefits to student learning with wearables. Wearables can provide students with learning data that is relevant to their life experiences, based on accurate interpretations of their data, and can also deliver learning content efficiently. For example, Lee et al. (2015) established that wearables provide students with relevant learning using body data for analysis in mathematics and science classes.

However, the relevance of the data also relies on the accuracy of the data. Without accurate data, students cannot make meaningful interpretations of the information they produce. Mehmood and Lee (2018) suggest that wearable devices already provide multimodal methods of accurate data analysis, especially when measuring the emotional states of children while learning. The combination of wearable-based sensor data that are relevant and accurate can benefit students as they gain rich insights *about* their learning to aid in self-reflection on *how* they learn.

Coupled with relevant, accurate data, the efficiency of data collection and analysis can also enhance student experiences with wearable technologies. Efficiency was addressed by Jones et al. (2003), who reported that 10 to 12-year-olds were able to quickly (within two hours) comprehend and begin applying wearable technologies in novel ways in new learning contexts.

Furthermore, Lee et al. (2015) observed that wearables increased the efficiency of data collection and improved the ability of elementary and high school students to explore mathematical concepts, such as graphing, calculating averages, and discussing distributions.

3.8.3 Learning

Benefits to student learning with wearable technology were collected from five articles. The learning theme includes two key factors: the application of wearables across learning domains, and the development of new beneficial pedagogies with wearables.

Three studies presented evidence that wearable technologies offer benefits for student learning across different learning domains in the K-12 context. First, Shadiev et al. (2018) assessed the use of smartwatches to learn English as a foreign language (EFL) and reported three outcomes: learning performance with smartwatches was significantly higher than learning performance without smartwatches, smartwatches significantly promoted student EFL learning, and students completed learning tasks better with smartwatches. In the second study, Merkouris et al. (2017) reported that wearable technologies helped improve the development of programming skills for 36 middle-school students. Third, Grawemeyer et al. (2017) tested affective-based feedback and performance-based feedback delivered through wearable technologies on 8 to 12-year-olds and found that students who received affective-based feedback showed improved learning outcomes. The results of these three studies suggest that wearable technologies apply to a range of learning contexts and can improve student learning across subjects.

The second wearable-based learning factor that benefits students is the impact of the technology on pedagogical approaches. The introduction of wearables in education has resulted in the emergence of new pedagogies. One example of an emerging pedagogy is referred to by Williamson (2015) as *biopedagogy*, which is the synthesis of sensor data into pedagogical thinking about health and physical education. The authors suggest that wearable sensors could encourage students to view their bodies as personal laboratories for experimentation and improvement and encourage individual students to develop a healthier body image (Williamson, 2015). The approach of biopedagogy is also supported by a survey of 437 high school athletes, in which individual students associated their ownership of a wearable fitness tracker with a stronger self-concept as a successful athlete (Ng & Ryba, 2018).

3.8.4 Engagement

Six articles reported that wearable technologies enhance engagement for students in a range of learning contexts. Siering et al. (2019) noted that a key benefit of wearable technologies is the real-time feedback that haptic or touch devices provide, which can improve student engagement in learning activities. Borthwick et al. (2015) added that wearable technologies allow learners to be engaged in customizable learning, anywhere and anytime, which extends the time and places where learning can occur. Kim and Searle (2017) reported that 12 to 14-year-olds who used wearable devices in collaborative learning were better engaged and also gained a better understanding of their community and the issues that affect it. Drew and Gore (2014) noted results from the Global Children's Challenge that 76% of teachers noticed a lasting, positive effect of wearables on student engagement and attitudes toward physical activity. Additionally, Hughes and Morrison (2018) observed that students in grades 3-9 who interacted with wearable devices, specifically with e-textiles in constructivist-based makerspaces, demonstrated improved engagement. Finally, Lindberg et al. (2016) added that the novelty factor of learning with exciting new technology (e.g., wearable devices) increased student motivation to learn and overall engagement.

3.8.5 Presence and Space

The theme of presence includes the benefits of using wearable technologies to overcome restrictions on where and when learning occurs. For example, Jones et al. (2003) observed 10 to 12-year old students' use of wearables to make digital comments on digital maps of public spaces, which in-turn provided other students with digital content to explore in those spaces. Their study illustrates how wearable technologies can empower students to explore new spaces, convert those spaces into areas for collaboration and communication, and bring digital presence and physical space closer together (Jones et al., 2003). On a more fundamental level, Bower and Sturman (2015) added that wearables free-up space for learning by removing the traditional wired-connection to a workstation, or desktop computer, thus making the learning experience more mobile and active for students.

3.8.6 Physical Needs

Another benefit of wearable technologies is the ability of wearables to bridge gaps in accessibility to learning materials, especially for students with unique physical needs or to students who live in geographically remote areas. For example, wearable gesture-capture devices help students who cannot physically input information through a keyboard and activity trackers support distance learners to participate in physical activities and assessments remotely (Borthwick et al., 2015) remotely. A key population of students can benefit from the affordances of wearable technologies to make learning more accessible and to help students overcome limitations of physical ability or physical distance.

3.8.7 Data Analysis

The seventh thematic benefit of children using wearable devices to learn is the inclusion of students in the process of collecting data. By including students in data collection processes, they gain a deeper understanding of the types of data collected, the data analysis process, and how to present data. Lee et al. (2015) conducted research to uncover two main advantages for including children in the data analysis process: students can passively acquire large amounts of data to construct an understanding of their learning, and students become intimately familiar with data-generating activities. The authors conclude that wearable devices can reduce the time required to teach students about data collection methodology, as the students have explicit knowledge of how and why the data was first produced (Lee et al., 2015).

3.8.8 Student Profiles

The final thematic benefit of students using wearable technologies to learn is the development of student profiles. Student profiles are digital collections of all the body data, and other forms of data students create through the use of wearable devices. The student profiles originated as a result of schools attempting to create a *datafication* of each student into a *quantified self* (Borthwick et al., 2015). While there is a risk of student profiles to be used in strict management of school populations, a key benefit of datafication is to create a clear visualization of students for better, targeted instruction and assessment (Borthwick et al., 2015). Additionally, Ng and Ryba (2018) support the benefits of student profiles and claim that quantifiable self-data enhances the understanding of student performance, and may also provide students with pre-emptive protection against school-related stress or burnout.

3.9 Challenges of Using Wearable Technology for Teachers

Eleven articles revealed six challenges specific to teachers considering the application of wearable technologies: determining engagement type, understanding applied design for learning, overreliance on technology, distraction and cheating, voice and the role of teachers, and security and privacy.

3.9.1 Determining Engagement Type

An important challenge for teachers is to understand different ways the communication functions of wearable technologies can be applied to enhance student engagement in learning. One of the key ways teachers can keep students engaged is through the use of self-tracking. Self-tracking requires students to pay attention to the learning goals outlined for a specific learning context, and then use their wearable devices to track their progress. The challenge for teachers is to understand the types of self-tracking best suited to promote engagement, as some of the self-tracking methods can have serious, negative implications on engagement. Lupton (2016) identified five modes of self-tracking that individuals can use to conceptualize their activities (see Table 4). The five modes of self-tracking could have an impact on student engagement in the K-12 context.

When applied to K-12 education, the first two types of self-tracking, private and communal self-tracking, could allow students to either determine their own learning goals or to formulate collaborative learning goals. Teachers can promote these two types of self-tracking in a student-centred approach to engagement. The third type, pushed self-tracking, would require teachers to have more direct involvement in sending reminders to students about learning goals. Pushed self-tracking is a form of engagement potentially more suitable for younger students in the K-12 age range. The last two types, imposed and exploited self-tracking, are problematic. Imposing tracking on students or using their trackable data can infringe on student privacy and voice, and these types of self-tracking may create a strict, teacher-centred approach to engagement. It is a practical challenge for teachers to be aware of self-tracking implications and to determine, with student input, the most appropriate form of self-tracking to encourage student engagement.

Table 4

A Typology of Five Modes of Self-Tracking

Mode	Description
Private Self-Tracking	Voluntary, self-initiated, personal reasons for use.
Communal Self-Tracking	Voluntary, shared reasons for use.
Pushed Self-Tracking	Applies pop-up messages or vibrations to encourage engagement.
Imposed Self-Tracking	Forced, externally initiated reason for use.
Exploited Self-Tracking	For commercial application of personal data only.

3.9.2 Understanding Applied Design for Learning

I used the theme *applied design for learning* to analyze how teachers can capitalize on the affordances of wearable devices to enhance pedagogical thinking in the creation of new learning environments. My review of the literature resulted in three factors that teachers can apply to the design of wearable-based pedagogies in K-12 contexts. The factors include free exploration of devices, student defined learning goals and ways of learning, and a shift away from empirical analysis to more anecdotal analysis of student learning data.

The first design challenge is to include a period of *messing around* in lesson designs, so students can explore the affordances of and become comfortable with new devices (Lee et al., 2015). However, teachers will need to account for this free exploration time and accept unstructured student learning in their lesson plans. The second design challenge is for teachers to promote activities that do not rely on rigid measurement and social constructions of what is normal (Drew & Gore, 2014). Teachers will have to balance a desire for open-ended student exploration, against the expectation to produce quantifiable data about student learning outcomes. The third design challenge is for teachers to focus on collecting data for pedagogical *why* aspects of learning, and to avoid collecting data only *about* learning and behavioural norms (Kumar et al., 2019).

3.9.3 Overreliance on Technology

One of the overarching challenges to teachers is to have a firm grasp of how wearable technology impacts pedagogy. The danger for teachers is to use technology for the sake of using technology and creating a culture in schools of *technology before pedagogy* (Bower & Sturman, 2015). Teachers run the risk of putting the affordances of digital technologies before pedagogical practice and overusing the technology in their classrooms. Bower and Sturman (2015) also noted that overreliance on technology can limit students' development of critical thinking skills, and may result in teachers treating technology as a one-size-fits-all, cure-all, solution to learning.

3.9.4 Distraction and Cheating

I extracted the distraction and cheating theme from one article. Bower and Sturman (2015) note that one aspect to consider when planning the use of wearable technologies in schools, is the potential for students to use the wireless internet functions, and discreet digital interfaces, to engage in off-topic behaviours. The challenge for teachers will be to think about how to prevent off-topic, distracting uses of wearables in K-12 learning contexts. Furthermore, Bower and Sturman (2015) point out the potential for wearable devices to be used by students in various ways to cheat during formal testing. Again, teachers will need to find creative ways to prevent students from using discreet wearable devices in inappropriate ways.

3.9.5 Voice and the Role of Teachers

Two additional challenges teachers face when planning to use wearables in K-12 contexts are to consider the voice of individual students in the interpretation of data and to maintain a critical role as educational professionals in the analysis of student data.

The first challenge is for teachers to consider how to balance their professional perspectives against the personal insights of their students when interpreting the data from wearables. The main risk for teachers is to rely on datafication to create one-dimensional profiles of students while ignoring the unique qualities of the students (Kumar et al., 2019). Also, Casey et al. (2017) suggest that there is a risk of teachers limiting the voice of students by forcing the students to create large *digital footprints* in the process of completing online learning activities. Teachers need to be aware of the type of personal data required by online learning programs and ensure students have the knowledge and ability to voice their concerns about the privacy of their online activity. Furthermore, Lupton and Williamson (2017) added that teachers must be careful not to restrict or influence student voice, and must not promote negative uses of wearable devices, such as data surveillance or making comparisons of student norms with the data.

A more existential threat to teachers is the challenge of maintaining their position as informed professionals among stakeholders vested in the development, application, and profitability of wearable devices. Lupton and Williamson (2017) noted the possibility for influential big data companies to overtake or displace the expert insights of teachers about student learning. For example, Roberts-Mahoney et al. (2016) analyzed government reports about education in the United States of America and found that teachers were increasingly viewed as coaches or data collectors in the K-12 context.

3.9.6 Security and Privacy

Borthwick et al. (2015) suggested that a primary challenge for teachers who implement wearable devices for learning in K-12 settings is to balance the use of student data for individual reflective use against collaborative applications for whole-class learning. Teachers will need to consider the security and privacy of student data before using it for learning. To address security and privacy issues, Borthwick et al. (2015) added two key challenges for teachers: to learn about the ethical use of digital technology and to teach students about digital citizenship to enable them to protect their privacy and the security of their data.

Furthermore, Lee et al. (2015) maintained that it is imperative to protect student identities connected to data collected from wearable devices. Otherwise, students may experience a negative impact on their mental health and wellbeing. Teachers will need to find ways to anonymize student data to protect from potential risks, such as bullying. Finally, Engen et al. (2018) noted that depersonalizing and anonymizing student data is challenging work, and teachers may need to undergo additional professional development about methods to safeguard sensitive student data.

Some solutions exist to address security and privacy issues, including the Children's Online Privacy Protection Act (Borthwick et al., 2015) and conducting all data analysis on school-based servers instead of through commercial companies (Choi et al., 2017). However, teachers still face considerable challenges in achieving effective, efficient use of wearables for learning while maintaining the security and privacy of student data.

3.10 Challenges of Using Wearable Technology for Students

Two articles (Borthwick et al., 2015; Drew & Gore, 2014) directly discussed challenges students might face when using wearable technologies and two themes emerged: student health and safety, and concerns about the collective and individual voice of students in the data they produce.

3.10.1 Health and Safety

One of the key reasons to use wearable technologies for learning in K-12 contexts is to protect student health and safety. However, there is some evidence that points to the possibility of wearable devices to create unhealthy, risky behaviour in children. Drew and Gore (2014) reported one unintentional outcome of wearable technologies is the creation of antagonistic body relations, where extreme competitiveness between students introduces a risk to their health and safety. As students push their bodies to achieve comparable and quantifiable outcomes with their data, they risk physical illness or injury to achieve better results than their peers. The challenge for students is to learn about healthy body relations and to exercise self-control and balance in their use of wearable devices, especially in physical education contexts.

3.10.2 Voice

It is important to be well informed about the potential limitations that wearable devices impose on the voice of students. Drew and Gore (2014) reported four challenges students face in the process of interpreting their body data. The challenges include the psychological conceptualization of oneself as normal or abnormal, the pressure to conform for the group ideal, emphasis on popular learning activities, and exclusion of unique student-created learning activities. In other words, students lose their voice when their data is compared to the whole group, and when novel ways of learning are disregarded. Drew and Gore (2014) summarized the challenge of voice, noting that wearable devices should not be used as simple measuring tools of student norms, but as a way to focus student reflections about their entire learning experience, as well as a way to promote a broader range of activities that interest individual students.

3.11 Attitudes Toward Wearable Technology (Teachers)

Limited research has been conducted on teachers' attitudes toward using wearable technologies for teaching and learning in K-12 contexts. However, Byun et al. (2018) reported that teachers had overall positive feelings toward using wearable devices as an effective and feasible teaching strategy in the classroom. Similarly, Lindberg et al. (2016) reported one teacher's positive attitude toward wearables as a way to understand and demonstrate key learning areas, such as the importance of physical education. Bower & Sturman (2015) added that wearable technologies enhanced positive social interactions through increased social presence via the chat functions on the devices. They also suggested that teachers' attitudes improved as student engagement improved.

More research needs to be conducted on teachers' attitudes toward wearable technologies because several issues negatively impact how teachers feel about wearables in K-12 contexts. Importantly, Kumar et al. (2019) warned that teachers' attitudes can also influence the culture of the classroom and how students perceive the use of wearables, such as the use of wearables to monitor and surveil peers. In summary, Engen et al. (2018) suggested that teachers' understanding of student privacy issues and cyber ethics will improve their overall attitude toward the use of wearable devices in the classroom.

3.12 Attitudes Toward Wearable Technology (Students)

I found three themes based on nine articles about students' perceptions and attitudes toward wearable technologies as learning tools: gender, design, and learning.

3.12.1 Gender

Research on gender differences in attitude toward the use of wearable technologies is mixed. Jones et al. (2003) reported that grade 5 and 6 female students were more concerned with social issues, such as privacy and security than male students when using wearables for learning. However, Merkouris et al. (2017), determined from questionnaire data of 36 middle school students in a computer programming class, that there is no significant difference of attitudes between boys and girls when learning to program through wearable devices. The authors also concluded that students preferred using wearable computers to learn computer programming skills when compared to traditional ways of learning, such as the use of desktop computers.

3.12.2 Design

Two design factors can impact student attitudes toward wearable devices: physical device design, and ease of use. At least two studies reported the overall rate at which students accept wearable technologies as learning tools when compared to other data collection tools (Mastrandrea et al., 2015; Siering et al., 2019). Additionally, Stehle et al. (2011) determined that students' attitudes toward wearable devices are based in part on the unobtrusive form factor of the devices. The ability to hide the devices on the body or in clothing is an important design feature for students who are concerned about the visibility of their learning devices, such as students with Autism Spectrum Disorder (Sahin et al., 2018). Furthermore, the perceived ease of use of the devices is another critical design factor that impacts students' attitudes toward using wearables to learn. Shadiev et al. (2018) reported interview data of 18 secondary school students in which the students felt wearable technologies improved the ease with which they accessed learning material, communicated, and participated in learning contexts.

3.12.3 Learning

How students perceive the learning process with wearable technologies may influence their general attitude toward the actual devices. Jones et al. (2003) noted an overall positive attitude of students toward wearable technologies to enhance education material delivery across different subjects. Kim and Searle (2017) reported interview results from 86 junior high school students in which the students agreed that learning with e-textiles was fun. Similarly, Lindberg et al. (2016) referenced interview data from a study of 61 elementary-aged students, in which one student claimed that using wearables to learn made him feel like a secret agent.

3.13 Practical Issues with Wearable Technology

My analysis of the literature resulted in five themes based on 20 articles that address the practical issues impacting the use of wearable technologies for teaching and learning in K-12 contexts. The practical issues are cost, security and legal, data analysis, data ownership, and design.

3.13.1 Cost

The primary costs associated with implementing wearable technologies for learning include the devices themselves, teaching educators to use the devices, maintenance, and purchasing up-to-date software. Bower and Sturman (2015) noted that the initial cost of providing wearable devices to schools pose a financial challenge to some schools. There are also device-related costs when registering for services required to operate the devices. For example, Lee et al. (2015) found two additional costs of implementing wearable technology in schools, namely the use of proprietary commercial services to analyze and access student data records, and expensive offsite storage of student data. Educators need to find creative ways to mitigate or reduce the costs associated with these services, or the use of wearable devices is not sustainable.

Professional development and maintenance costs are also challenging. Bower and Sturman (2015) reported interview data on eight veteran teachers and found that the teachers were most worried about a lack of adequate technical support when implementing wearable technologies in K-12 contexts. Additionally, Engen et al. (2018), expecting teachers to become familiar with network technologies (e.g., Wi-Fi routers) is time-consuming, frustrating, and costly in terms of time.

Schools and teachers will also have to maintain the devices and maintain the supply of wires and batteries in makerspaces. Ngai et al. (2013) surveyed two significant material maintenance costs of wearable devices and found there is a lack of reusable toolkits for makerspaces on the market, and consumable electronic parts used in the development of wearable e-textiles can be expensive.

A final cost issue is the requirement to purchase up-to-date software for the efficient use of wearable devices. More specifically, Bower and Sturman (2015) noted the potentially high cost of producing student-centric programs and software that target the unique learning needs and requirements of individual students.

The cost challenges referenced above have contributed to a low level of wearable device ownership among students and the unequal implementation of wearable technology in some K-12 contexts (Engen et al., 2018). Unequal access to devices can affect the learning experiences of students in different socioeconomic backgrounds, and also cause a disparity of experience with wearable technologies between learners (Borthwick et al., 2015; Hughes & Morrison, 2018). More research is needed to address how to close the divide between the level of access to wearable devices that different groups of students experience.

Conversely, there are also potential cost savings associated with implementing wearable technologies in schools. Bagot et al. (2018) suggested that, historically, new technologies were significant and required structural changes to school facilities, but current wearable technologies do not need these expensive alterations. Furthermore, Byun et al. (2018) noted that cloud-based storage of student data reduces the cost schools pay for the installation of on-site storage servers, computer maintenance, and facility maintenance. Implementing wearable technologies in schools requires careful fiscal planning and responsibility for training and maintenance; however, the wearable technologies require less investment into construction and physical infrastructure overall.

3.13.2 Security and Legal Issues

I found three articles that include specific references to the security of data as a critical, practical issue for both students and teachers. Lupton and Williamson (2017) are critical of security issues, noting that hacking attacks are increasingly common-place events that threaten the security and privacy of personal data. The authors also stated that there is a lack of literature informing teachers about effective ways to protect student rights. Schools may have to take on the burden of ensuring the protection of student data. However, the immediate solution for implementing strict network security (such as internet firewalls) may not be effective. For example, Lee et al. (2015) suggested that relying heavily on digital firewalls to prevent hacking can limit access to learning information, other devices, and ultimately frustrate teachers and students.

Solving the issue of security is a key factor for schools as the ramifications of failing to protect student data can result in legal challenges and lawsuits from parents. Furthermore, Bower and Sturman (2015) note that providing teachers with professional development in the legal and ethical issues surrounding wearable technologies is an absolute requirement for the effective application of the technologies in schools. However, this may place stress on school administrators as they consider how, when, and where to upskill teachers, as well as the implications paid professional development has on school budgets. More research is required to help schools develop professional development programs to inform and protect teachers from potential data security-based legal issues.

3.13.3 Data Analysis

Another practical issue of using wearable technologies to collect data from students in K-12 environments is understanding how the data is analyzed. Specifically, there is a potential for underlying social biases or other ulterior motives on the interpretation of student data.

Byun et al. (2018) suggested that the challenge to overcome data analysis bias is to develop a socially constructed, democratic synthesis of student data that accounts for social biases. However, Williamson (2016) contended that even socially constructed, democratic data synthesis is not neutral, and underlying social values may continue to skew the data outcomes. Furthermore, Roberts-Mahoney et al. (2016) reported that there is a general trend in the education field toward reducing all learning and behaviours into quantifiable skills for database storage and comparison of students. Di Mitri et al. (2018) added three complications to data analysis, including a lack of understanding of how to support learning with data, difficulty in synthesizing increasing amounts of data, and the ambiguity of literature from different professions about data analysis. More research is required to inform the development of efficient methods of data analysis that account for social biases and the accurate synthesis of student data for clear educational goals.

3.13.4 Data Ownership

Data ownership is another practical issue that requires careful consideration before implementing wearable devices in K-12 schools. Lupton and Williamson (2017) noted the criticism that companies profit from the data analysis services they provide to schools and may retain ownership of student data for non-academic, commercial purposes. Commercial ownership of student data may then limit how children, parents, and teachers access and control the privacy of the data (Borthwick et al., 2015; Lupton, 2015).

Furthermore, Selwyn (2015) warned that the algorithmic analysis of students and educational problems might shift schools away from a holistic understanding of students, and lead to the *statistical solutionist* management of students. The concern is that students will become the producers of data, and commercial entities or schools will become the users of data to control students. Selwyn (2015) also identified four potential dangers of statistical solutionist management styles in education: reproduction of social inequity in data ownership, intensive management of schools through strict data analysis, increased statistical profiling and discrimination of students, and reduction of contextual, environmental, and unique student voice in data analysis.

In summary, the challenge is to develop a way to analyze data gathered from wearable technologies that emphasize both quantitative and qualitative data, while maintaining equity of ownership between teachers and students (Gilmore, 2015).

3.13.5 Design

My review of six articles revealed three types of design issues that can impact the application of wearable technologies in K-12 contexts: physical device design, the effectiveness of device embedded sensors, and how to deliver information through wearable devices.

The first issue is how to determine the best physical design of wearable devices for teaching and learning. There are four common design factors for gauging physical device usefulness: processing capacity, connectivity, battery life, and interface tactile control (Bower & Sturman, 2015; Plazak & Kersten-Oertel, 2018). There are also four unique design factors for gauging device usefulness: user familiarity with the device interface, visibility (covertness) of devices, how well the device fits, and the ruggedness of the device (Bower & Sturman, 2015; Plazak & Kersten-Oertel, 2018).

Another design issue is how well sensors can accurately and efficiently produce data for synthesis and analysis. Dahlstrom-Hakki et al. (2019) found two practical challenges when using sensor-rich wearable devices for teaching and learning: difficulty calibrating sensors on multiple devices in a single learning context, and the introduction of measurement error from excessive movement or lighting. Similarly, Grawemeyer et al. (2017) reported that speech and voice recognition sensors suffered from low accuracy due to the variability of speech and interference from environmental noise. Interestingly, Egger et al. (2019) suggested that sensor data might be skewed by students masking their true physiological responses based on social or cultural norms. Sensor data, though, needs to be accurate to guide learning effectively. To address these sensor issues, teachers will need to gain a working knowledge of measurement errors when designing learning activities.

The last design issue is to ensure the efficient and effective delivery of information via wearable technologies to learners. One aspect of the delivery design issue is to consider the overall learning process, including factors that cause stress for students. Labus et al. (2015) noted the danger of ineffective delivery of information via wearables, suggesting that wearable devices must provide intuitive user experiences to prevent increased cognitive load on learners. Finally, Grawemeyer et al. (2017) concluded that teachers must find the combination of feedback delivery and feedback type students respond to best, and focus on developing student-centric learning programs that capitalize on those delivery methods.

3.14 Summary of Results

The results of my systematic review of the literature on wearable technologies for teaching and learning in K-12 contexts netted a broad mapping of pertinent issues through a thematic narrative analysis of empirical and non-empirical evidence from 52 articles. The data revealed five broad categories of themes about the use of wearable technologies: pedagogical uses, benefits, challenges, attitudes, and practical issues, and included detailed insights through two perspectives of analysis (i.e., teachers and students).

Pedagogical uses of wearables in real-world learning contexts were evident in 16 articles. These learning contexts showed that wearable devices could be applied in a range of subjects to improve how learning is presented by teachers and engaged in by students. Wearables helped to monitor child physical safety, as well as environmental factors on their health and neurodevelopment. Wearables also to improved the emotional experience of learning by targeting academic emotions for better affective-based teaching and learning strategies. The flexibility and mobility of wearables proved useful in developing multimodal learning environments such as makerspaces, game-based and simulation-based learning contexts. Additionally, wearables predicted future academic achievement in different subjects, which has helped teachers develop more engaging student-centred learning experiences.

Teacher and student perspectives on the benefits of using wearable technologies were assessed. The research showed that teachers benefit from using wearables by developing more holistic pedagogical thinking with exploration and adventure at its core. Teachers can also benefit from wearables in the development of cross-subject learning experiences that are efficient and targeted to the individual needs of each unique student. The real-time playback of audio and visual recordings resulted in better, self-reflective professional development and teacher training.

Students benefitted from using wearables in at least six ways. Wearables amplified the voice of marginalized students, improved access to learning materials for students with physical needs or geographical limitations, provided anytime-anywhere access, offered assessment feedback in real-time, increased understand learning through exploration of self-generated body data, and made learning more fun and relevant.

Teacher and student perspectives on the challenges of using wearable technologies were also assessed. Teachers experienced six challenges: learning about the affordances of wearables to determine the best form of engagement for students, gaining in-depth knowledge of different pedagogical approaches for using wearables, tempering the potential overreliance on wearables as a quick-fix for learning, preventing the misuse of the technology by students, protecting student data with newly developed security and privacy policies, and considering their voice as knowledgeable professionals in the interpretation and use of data, while also accounting for students voice. Students faced two main challenges that could have serious consequences on their physical and mental health. Wearables might lead to hyper-competitive notions of education and lead some students to develop unhealthy body practices to outperform peers. Wearables may also affect the mental health of students who feel stress to conform to forced dichotomies of normal versus abnormal body data. The greatest challenge is for students to express a clear voice in the interpretation of their body data.

Attitudes of teachers and students toward the use of wearable technologies were mixed. More research is required on both teacher and student attitudes; however, available data show teachers had a generally positive attitude toward wearables in K-12 contexts. Teachers found the technology was useful for enhancing participation, collaboration, and presentation of learning materials. A key issue to note is that teachers' attitudes toward wearables for teaching and learning can have a substantial impact on students' attitudes toward technology. Additionally, some evidence suggests there might be gender differences regarding the level of concern for data privacy when using wearables, but that boys and girls equally preferred learning with wearables versus traditional mediums. Furthermore, the physical design and ease of use of devices were essential factors in determining students' attitudes toward wearables. Importantly, there is some evidence to suggest that students generally view learning with wearables as fun learning.

Finally, the practical issues affecting the use of wearable technologies were summarized into five themes: cost, security and legal, data analysis, data ownership, and design. The cost of wearable devices, training teachers to use wearables, maintenance, updating software posed significant challenges. However, some evidence suggests that wearables represent a more cost-effective choice over time. There were also security and legal issues. These challenges represent a significant area of research and additional training for teachers to be up-to-date on data ethics and security policies to avoid potential legal implications of mishandling student data. Other issues were biased data analysis of student data and determining ownership of student data, especially when commercial entities have access. The last practical issue included three types of design challenges: device design, sensors, and delivery. I found several factors that could affect the design of the actual wearable devices, but no data on design factors stemming from the field of education. Sensors also presented a challenge, as some sensors are prone to environmental factors that skew data and can impact the accuracy of the data. The last design issue I found was to create an appropriate balance between the delivery of information to keep students engaged while preventing an increase in cognitive load on students.

4. Discussion

4.1 Limitations and Future Research

There are at least 11 limitations and opportunities regarding research on the use of wearable technologies in K-12 environments. The first limitation is the nature of the studies themselves. There is a fundamental lack of empirical research and quantifiable data in the field, which resulted in my methodological approach to treat study data from a thematic-narrative perspective. Only 32 studies collected empirical data regarding the use of wearable devices. Therefore, at an outcome level, my synthesis and conclusions are limited to qualitative interpretations. Future research needs to include reliable, valid and fulsome assessment of attitudes and learning outcomes associated with the use of wearables devices.

In addition, the specific grade levels and subject areas within K-12 environments are not evenly represented, with most of the research focusing on elementary school environments. Future research needs to broaden the scope of analysis concerning grade level and domain.

Another limitation is the emphasis of this review on teachers and students only. Other perspectives found in the literature but not expanded on here include stakeholders such as parents, school administrators, government, big-data companies, device designers, application developers, and other stakeholders from a range of professional fields. Each perspective introduces new insights and challenges regarding the application of wearables in K-12 contexts. Future research can look at ways to achieve synergy and equity of voice between stakeholder groups about the use of wearables in K-12 education.

Additionally, there are specific gaps in the literature for the following themes: learning, design, data analysis, data ownership, student health, attitudes, and gender. I identified three aspects of teaching and learning with wearable technologies in K-12 contexts that require more research. First, the concept of academic emotions and affective learning with wearables suffers from discrepancies in definitions and a lack of empirical data. More data is needed regarding the defining and detection of academic emotions, and the application of affective-based learning strategies through the use of wearable devices. Second, few studies examine the blending of different types of wearable technologies and subject matter to create multimodal learning contexts. Future research can test the effectiveness and feasibility of multimodal learning with wearables. Third, more studies are needed regarding simulation with wearable devices in K-12 contexts. Researchers can examine how different types of wearables might be used for simulation-based learning.

The second thematic gap in the literature is a design issue. While there is some data regarding physical design elements that are essential in developing effective wearable devices, more research is needed to determine specific design elements for wearable devices targeted at K-12 learners. Furthermore, additional research could examine the cost-benefit analysis of wearable devices currently on the market, keeping in mind the issues of socio-economic inequity and special needs for some learners.

Third, the data analysis theme introduced the issues of bias and limiting student voice. Future research can target the quality of analysis methods and suggest ways to account for and reduce biased interpretations of data. Also, researchers can attempt to formulate models of communication between students and teachers in which students maintain their voice in determining the use and meaning of their body data.

Fourth, the data ownership theme uncovered a requirement to determine ways of protecting student data and ensuring that students have control over the data they produce through wearable devices. Researchers need to develop protection strategies for student data while also considering the legal and ethical implications of data ownership issues.

Fifth, student health issues are also a key area for future research. My review uncovered risks to student mental and physical health after using wearable technologies. However, more research is needed to uncover potential, unintended negative implications of wearable device use on student psychological and physical health.

Finally, it is worth noting that very little data is available regarding teachers' attitudes and gendered attitudes of students toward wearable devices for K-12 teaching and learning. Future research can investigate a larger population of teachers and students across the K-12 grade levels for a deeper understanding of their attitudes toward wearables.

4.2 Conclusion

Taken together, the themes presented in this review intersect to illustrate an emerging field of research full of practical benefits and challenges, as well as higher-order philosophical, pedagogical, and social areas to explore and evolve. While much of the literature points to the benefits of wearable technologies to enhance effective praxis for teachers and better learning experiences for students, there remains a catalogue of challenges to overcome as well. To address the challenges, teachers need to orchestrate their professional insights, ideas, and learning goals with an appreciation for the opinions and self-reflective voice from individual students.

The essential goals for educators interested in wearables for teaching and learning in K-12 contexts are: to safeguard body data of children against the backdrop of bio-pedagogical, proprietary and socio-political interference, and to vigorously focus on creative applications for different wearable technologies across multiple learning domains. If wearable technologies become ubiquitous in K-12 learning contexts, the potential outcome is the creation of a truly democratic form of learning, informed by expert insight, fresh philosophical thinking, and engaging, efficient, and effective pedagogical praxis. In the hands of students, wearables have the potential to be a tool for the construction of student-centred, collaborative, and novel learning experiences. Experiences that go beyond the walls of the classroom and foster experimentation and entrepreneurial passion in education.

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APPENDICES

Appendix A

Sensor Type Descriptions for Wearable Devices

Sensor Type	Sensor Description
Electrocardiography (ECG)	The primary sensor used in detecting heart rate variability (HRV). The ECG sensor is able to detect the temporal change in heart rate between each beat of the organ. Furthermore, this type of sensor is important as it can detect emotions on its own with a measure of reliability across two metrics of accuracy (Egger et al., 2019). A reasonable application of this type of sensor would be in any device worn on the body where heart rate is detectable, such as a smartwatch, neckband, or stitched into a layer of clothing.
Electrodermal Activity (EDA)	This sensor requires the application of two electrodes housed inside of a wearable suited for covering at least one finger. This could take the shape of a single finger-sized clip or full glove. The electrodes measure conductivity or electrical skin resistance, and the resulting data can be used to measure overall **arousal state of the human body**. It is suggested to combine EDA data with other sensor data to detect **emotional states** (Egger et al., 2019).
Skin Temperature (SKT)	A sensor designed to measure arousal levels within the human body. The physiological process of blood vessel dilation allows the **measure of skin temperature**, commonly at the finger-tip. **Constricted blood vessels will make the body colder**, which is associated with **stress and anxiety**. Conversely, when the vessels dilate to open blood flow, the **body gets warmer, which is indicative of a relaxed emotional state** (Egger et al., 2019). This type of sensor could also be fitted to a smart glove or single finger clip or band.
Blood Volume Pulse (BVP)	This sensor capitalizes on the use of Photoplethysmography (PPG), which are light-emitting and photo-diodes able to record the waveform of the user's pulse. **The BVP sensor is an additional method to measure heart rate variability** (HRV) and is often found in smart wearables for active settings, such as smartwatches, though it can be applied anywhere on the body (Egger et al., 2019).

Respiration (RSP)	This sensor relies on the thoracal activity of the human body while breathing. Sensors can take on a number of shapes, forms, and sizes, and can be used to **detect respiration frequency**. Different patterns of respiration are associated with different **emotional states**. For example, heavy breathing at a fast rate is associated with happiness or fear (Egger et al., 2019). Sewing an RSP measuring device into clothing is one wearable form this sensor can take on.

Appendix B

Themes and Categories for Analyzing Data in Literature Review

Original Theme in First Analysis	Main Category	Sub Category
Academic Emotions	Pedagogical Use	Student Health and Safety
Accuracy	Pedagogical Use	Learning
Applied Design for Learning	Pedagogical Use	Body Movement and Environment Monitoring
Body Movement	Pedagogical Use	Prediction of Learning Outcomes and Diagnosing Academic Emotions
Cheating	Teacher Benefit	Design
Cost	Teacher Benefit	Data Analysis and Efficiency
Data Analysis	Teacher Benefit	Engagement
Design	Teacher Benefit	Professional Development
Engagement Types	Student Benefit	Voice, Ownership, and Self-Reflection
Distraction	Student Benefit	Relevance, Accuracy, and Efficiency
Efficiency	Student Benefit	Learning
Engagement	Student Benefit	Engagement
Environment Monitoring	Student Benefit	Presence and Space
Gender	Student Benefit	Physical Needs
Health	Student Benefit	Data Analysis
Learning	Student Benefit	Student Profiles
Legal	Teacher Challenge	Determining Engagement Type
Overreliance on Technology	Teacher Challenge	Understanding Applied Design for Learning
Ownership	Teacher Challenge	Overreliance on Technology
Physical Needs	Teacher Challenge	Distraction and Cheating

Prediction of Learning	Teacher Challenge	Voice and the Role of Teachers
Presence and Space	Teacher Challenge	Security and Privacy
Privacy	Student Challenge	Student Health and Safety
Professional Development	Student Challenge	Voice
Relevance	Student Attitude	Gender
Role of teachers	Student Attitude	Design
Safety	Student Attitude	Learning
Security	Practical Issue	Cost
Self-Reflection	Practical Issue	Security and Legal Issues
Student Profiles	Practical Issue	Data Analysis
Voice	Practical Issue	Data Ownership
	Practical Issue	Design