The use of smart wearables in primary and secondary education: A systematic review

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Abstract

The aim of this literature review was to examine the empirical evidence for the use of smart wearables in primary and secondary education between 2010 and 2020. The initial search yielded 1.868 results, from which a total of 15 articles were included in the final analysis. Major findings include that most studies used devices such as smart watches and fitness trackers. About half of the reviewed studies do not refer to any learning theory or other pedagogical background. Moreover, in many studies there are several learning outcomes from using smart wearables in education, such as improved performance, increased motivation, and attitudes towards learning. Despite those findings though, the existing research on the use of smart wearables in education is still in its early phase. Therefore, future research should be enriched with more methodological rigor and longitudinal studies in order to correlate the impact of smart wearables on students' learning with variables such as the type of device, learning environment, subjects, and learning theory. The findings of this literature review may provide insights for researchers and teachers into the use of smart wearables in education.

Keywords: Wearable technologies, wearable devices, learning, primary education, secondary education

Introduction

The rapid growth of wireless technologies and the Internet of Things has resulted in the increased development of compact electronic and computing devices that can be worn on individuals' bodies (Niknejad, Ismail, Mardani, Liao & Ghani, 2020). These devices are known as smart wearables (Niknejad et al., 2020; Pal, Vanijja, Arpnikanondt, Zhang & Papasratorn, 2019), wearable technologies (Bower & Sturman, 2015), or wearable devices (Geršak et al., 2020), allowing for interaction between users and the smart environment anytime and anywhere (Dehghani, Abubakar & Pashna, 2020). Examples of smart wearables are smart and sports watches, fitness trackers, smart glasses, smart fabrics, and smart jewelry (Pal et al., 2019).

Smart wearables have recently generated an increased interest in their benefits and constraints across many fields, such as health and medicine, fitness, disabilities, gaming, and enterprise (Tehrani & Michael, 2014; Niknejad et al., 2020). This increased interest is due to the characteristics of these technologies. Among these characteristics are portability (Bower & Sturman, 2015), embedded software (Zhang, Wu, Fournier-Viger, Van & Tseng, 2017), different types of sensors (e.g., environmental, biosensors, position and location tracking sensors) (Mardonova & Choi, 2018), as well as the capability to connect to other devices, for example smartphones (Demir & Demir, 2017).

Although smart wearables are less widespread in the field of education compared to other fields (e.g., medicine, fitness), nonetheless, many researchers (Garcia, Chu, Nam & Banigan, 2018; Kalantari, 2017; Lee & Shapiro, 2019; Mewara, Purohi & Rathore, 2016) claim that they are an emerging technology whose utilization may provide added value to formal and informal learning environments. According to Bower and Sturman (2015), this added value lies in the unique features of smart wearables. These characteristics, which can serve as educational affordances, include among other things, hands-free access, presence, in situ contextual information, first-person view, and in situ guidance. Furthermore, Borthwick, Anderson, Finsness and Foulger (2015) claim that this value can add to student engagement (e.g., students can use smart glasses to experience an augmented field trip), a universal learning design (e.g., while a student points to a text, a wearable device "reads that text aloud", which means that wearables can be useful in all kinds of learning styles), special education (e.g., students with autism use facial recognition software for smart glasses to recognize the emotions of other people in school), administrative functions (e.g., students can use smart watches to remind them about homework deadlines), and student profiles (e.g., smart glasses can be used to monitor students' activities and therefore identify which of them have exceptional abilities). Additionally, Buchem (2019) claims that wearables have embodied affordances that support embodied learning, making wearable enhanced learning unique compared to other technologies that also offer enhanced learning experiences. These embodied affordances include capabilities that allow: (a) the user to see through the eyes of a virtual body, (b) the virtual body to react accordingly based on user's actions, and (c) the user to interact with represented entities such as artefacts in augmented, virtual and mixed reality environments by examining, manipulating, and rearranging them. Finally, Motti (2019) supports that wearable technologies add a new engaging element to teaching. She points out that head-mounted displays help students immerse themselves virtually in real-world scenarios, and therefore provide them with a full-body experience to learn while wrist-worn devices are lightweight and easy to access, enabling students to access information instantly and in an unobstructed way.

Nevertheless, it appears from a search of extant literature that a systematic review of the use of smart wearables in primary and secondary education, as well as their impact on learning and teaching has not been conducted. This paper is one of the first that aims to systematically review the use of smart wearables in the first two levels of education. As will be presented in a next section, previous reviews regarding smart wearables have looked at a positive impact in a non-educational setting. For instance, Kolodzey, Grantcharov, Rivas, Schijven and Grantcharov (2016) examined the literature on the use of wearable technology (e.g., Google Glass, GoPro, or customized head-mounted displays) in surgery, both in clinical and simulated experimental settings. Wei, Dougherty, Myers and Badawy (2018) conducted a systematic evaluation of the literature on the feasibility and acceptability of using Google Glass in surgical settings and assessed the potential benefits and limitations of its application. Mardonova and Choi (2018) reviewed current trends in wearable device technology and provided an overview of its prevalent and potential deployments in the mining industry. In a more recent study, Niknejad et al. (2020) reviewed 244 studies from 2010 to 2019 whose subject was smart wearables in various fields (e.g., healthcare, industry, military, automotive, manufacturing). The current review aims to address the existing gap regarding the use of smart wearables in educational settings. Therefore, the purpose of this systematic review is to examine the existing research regarding smart wearables in primary and secondary education, highlight research gaps, and make suggestions for future research on their use in formal and informal learning environments.

The following research questions (RQ) were defined in relation to research involving the use of smart wearables in education:

RQ1: Which smart wearables were used?

RQ2: What were the learning environments and in what subjects were smart wearables used for?

RQ3: In which level of education were smart wearables used?

RQ4: Which were the learning theories applied by the studies?

RQ5: What research methodology was used?

RQ6: What were the learning outcomes?

RQ7: What factors influenced the use of smart wearables?

The review study is organized as follows. The next section presents the definition of smart wearables and their main categories. Following that, previous research studies are presented. Then, the methodology for the literature review is presented. In the section after that, the main findings of the review are presented. The subsequent section discusses the findings of the literature review and highlights research gaps. The section after that describes the review's limitations. The next section offers general conclusions and the last section focuses on future research studies regarding the use of smart wearables in education.

Definitions and categories of smart wearables

Smart wearables are the result of two significant technological developments: ubiquitous technology and embedded technology (Viseu, 2003). Barfield and Caudell (2001) define wearable computing as a "fully functional, self-powered, self-contained computer that is worn on the body … [and] provides access to information, and interaction with information, anywhere and at any time" (p. 6). Over time, the word "computers" has been replaced by the word "technologies". Bower and Sturman (2015) define wearable technologies as "wearable digital devices that incorporate wireless connectivity for the purposes of seamlessly accessing, interacting with, and exchanging contextually relevant information" (p. 344). Jeong, Kim, Park and Choi (2017) give a more straightforward definition: "wearable devices refer to any electronic device or product designed to provide a specific service that can be worn by the user" (p. 400). More recently, Geršak et al. (2020) defined wearables as "multiparameter devices capable of monitoring and recording user's kinetics, kinematics, physical parameters and/or (psycho)physiological parameters" (p. 582). In their literature review paper, Niknejad et al. (2020) use the term "smart wearables" to include studies on wearable technology or wearable devices. In this study, the terms "wearable technology", "wearable devices" and "smart wearables" are used interchangeably.

In terms of the classification of wearables, it seems that researchers categorize them in several ways (Niknejad et al., 2020). Some researchers, such as Dimou, Manavis, Papachristou and Kyratsis (2017), categorize wearables according to their use (e.g., entertainment, lifestyle, fitness, medical, industrial, and gaming) and others (Pal et al., 2019; Tehrani & Michael, 2014; Yang, Yu, Zo & Choi, 2016) according to the type of the device. For example, Yang et al. (2016) categorize wearables into three groups: necklace or wristband-type, watch-type, and head-mount display-type. According to Mewara et al. (2016), the classification of wearables is based on two factors: the part of the body on which they are worn (namely head-mounted, body-dressed, hand-worn, foot-worn), and their functionalities (i.e., fitness, medical, lifestyle, gaming, infotainment). Recently, Dian, Vahdnia and Rahmati (2020) classified IoT enabled wearables, based on their applications, into the following categories: health, sports and daily activity, tracking and localization, and safety.

Previous review studies

There are many reviews on the use of smart wearables in various fields such as medicine (e.g., Kolodzey et al., 2016; Wei et al., 2018), physical activity (e.g., Girginov, Moore, Olsen, Godfrey & Cooke, 2020; Kirk, Amiri, Pirbaglou & Ritvo, 2019; Yen & Chiu, 2019), sports (e.g., Santos-Gago, Ramos-Merino, Vallarades-Rodriguez & Álvarez-Sabucedo, 2019), neuroscience (e.g., Johansson, Malmgren & Alt Murphy, 2018), and work environment (e.g., Khakurel, Melkas & Porras, 2018).

The following are indicative reviews from each of the above-mentioned fields. For instance, in the field of medicine, Wei et al. (2018) investigated the feasibility and acceptability of using Google Glass in surgical settings, as well as the potential benefits and limitations of its application. They analyzed 31 studies published from January 2013 to May 2017 and concluded that there are promising feasibility and usability data regarding the use of Google Glass in surgical education and training. Although studies report limitations (e.g., short battery life, difficulty with hands-free features, data privacy concerns) Google Glass was generally well-received. In fact, several studies in surgical settings acknowledged its potential for training, consultation, patient monitoring, and audiovisual recording. In the field of physical activity, Girginov et al. (2020) addressed the question of whether wearable technology can enhance social interactions that affect people's physical activity. They reviewed 20 studies published from 2007 to December 2018 and found that wearable technology has the potential to both motivate and demotivate individuals to engage in physical activity. Also, the researchers report there is no evidence that using wearable technology promoted physical interactions. Finally, they concluded that these interactions are temporary, physically organized, and can be repeated in different contexts.

Santos-Gago et al. (2019) explored 26 articles, published from January 2015 to August 2019, to explore the proposals regarding the innovative use of wrist-worn wearable devices that exist in the sports field. According to the reviewed studies, the most common purposes of wearable devices in sports are related to monitoring and classification of sports activities. Also, wearables are used to identify specific types of movements or actions in specific sports, and to prevent injuries. The researchers explain that monitoring an athlete's variables, as well as his or her behavior, can be related to his or her performance. In the case of wrist-worn wearables, such as smart watches and fitness trackers, it is their portability and possibility of transparent use that facilitates the observation of an athlete while training or competing.

In neuroscience, Johansson et al. (2018) reviewed 56 quantitative and qualitative clinical researches, from 1995 to January 2017, using wearable sensors in cases of epilepsy, Parkinson's disease, and stroke. More specifically, in epilepsy wearables were used to detect and differentiate seizures in hospital settings, while in strokes they were used to monitor upper extremity activity, walking, and physical activity in the laboratory and during leisure activities. In Parkinson's disease, studies focused on quantification of cardinal motor symptoms and medication-evoked adverse symptoms in both the laboratory and free-living environment. According to the researchers, wearables may provide information on clinical features of interest in epilepsy, Parkinson's disease, and stroke. However, they also point out that knowledge regarding the clinical utility for supporting clinical decision making remains to be established as there weren't any studies that directly addressed the question of the effect wearables may have on decision making or clinical treatment outcomes.

Khakurel et al. (2018) researched studies from 2000 to 2016 on the use of wearable devices in various workplaces (e.g., office, construction, agriculture) to study the possibilities they offer as well as the challenges arising from their use. They analyzed 34 studies and found that smart wearable technology has the potential to increase employee productivity, improve their physical well-being, and reduce any work-related injuries.

One of the most recent and extensive literature reviews on smart wearable technologies is that of Niknejad et al. (2020). They analyzed 244 studies from 2010 to 2019 including articles in journals, paper conferences, and articles in a book. They aimed to explore which are the research themes of the studies, which are the theoretical adoption models and frameworks applied by the studies, and which are the factors that affect behavioral intention and adoption of smart wearables. According to their findings, research on smart wearables has dramatically increased in recent years, with medicine being the dominant field. They found that the most common research themes are technology-focused, user behavior, design, social acceptability, security, and privacy. Also, the majority of studies are quantitative. Regarding the theoretical adoption models and frameworks applied by the studies, it was found that the majority used the Technology Acceptance Model. Furthermore, the researchers found that perceived usefulness is the influencing factor for the adoption of most smart wearables. Other influential factors are privacy concerns, perceived enjoyment, and perceived ease of use. Of the 244 reviewed studies, only three of them were conducted in a primary or secondary education context and aimed to investigate, among other things, the impact of smart wearables in learning. However, these studies are not thoroughly presented by researchers. Moreover, this systematic review has some limitations. According to Niknejad et al. (2020), since these studies were reviewed in March

2019, not all papers published since then may have been covered. Furthermore, only two databases (i.e., Thomson ISI's Web of Science and Elsevier's Scopus) were used to review the literature.

Method

The literature review was conducted between April 22nd to May 1st, 2019, and again on April 7th, 2020, via an electronic search using international online databases. The databases accessed were Scopus, ERIC, SpringerLink, ACM Digital Library, Emerald, Web of Science, ScienceDirect, Learning and Technology Library, and IEEE Xplore. Considering that the biggest technological "boom" in smart wearables occurred from 2010 onwards, the database filter for the publication period was set from 2010 to 2020. At that time, more specifically at the end of 2009, Fitbit trackers were released for purchase (Comstock, 2015). Fitness activity trackers, such as Fitbit, are considered to be the first generation of wearables to be widely used (Dian et al., 2020). Hence, from that time onward research activity on smart wearables has been conducted more and more.

The following search terms were used: "smart wearables" OR "wearable technologies" OR "wearable devices" AND "education" OR "learning" OR "teaching." This review was limited to databases that were open accessed or to databases accessed through the authors' institutional library. The literature research was based on the PRISMA principles (see Moher, Liberati, Tetzlaff, Altman & The PRISMA Group, 2009). The inclusion criteria for all research questions were: (a) the articles and papers must be conducted in actual educational settings in primary or secondary education, (b) the articles and papers should be written in English and (c) the articles and papers should provide empirical data from a sample of pupils, analyze the data, and interpret the results. The search resulted in 1.882 articles and papers, excluding the duplicates. After the initial screening, 1.679 were excluded because of their irrelevant title, keywords or abstract, and another 14 were excluded because they referred to medical education or were not written in English. After full-text eligibility checking, 174 were also excluded as they were not relevant to the aim and research questions of the current review. In total, 15 articles were ultimately found to be relevant and used to report the impact of smart wearables on education. Figure 1 presents the flow of information through the articles that were selected. These articles have been analyzed according to the aforementioned research questions. This analysis scheme was divided into seven categories: (1) wearable device, (2) learning environment, (3) subject, (4) education level, (5) pedagogical foundation, (6) methodological design, and (7) main findings (see Table 1).

Findings

Table 1 presents the findings of the 15 selected studies on the impact of wearable technologies on education. In particular, the purpose of each study, the device used, the learning environment, the subject, the level of education, the learning theories, the methodology adopted, and the main results are presented. A more detailed analysis of these studies is presented in the following sections by answering each research question.

Wearable devices

As far as the first research question is concerned, the current review showed that there is a variety of wearable devices currently utilized. Smart watches were used in six of the studies (Amin, Inayat & Shazad, 2015; Chu & Garcia, 2017; Engen, Giæver & Misfud, 2017; Garcia et al., 2018; Lindberg, Seo & Laine, 2016; Shadiev, Hwang & Liu, 2018). Fitness trackers were used in three studies (Byun, Lau & Brusseau, 2018; Kerner & Goodyear, 2017; Lee, Drake & Thayne, 2016). Also, two studies investigated the impact of smart glasses (Kuhn et al., 2016; Lukowicz et al., 2015). Another three studies refer to the use of smart textiles (Barker et al., 2015; Merkouris, Choriamopoulos & Kameas 2017; Nugent et al., 2019). Finally, another one used a wearable arm bracelet (Balestrini et al., 2014).

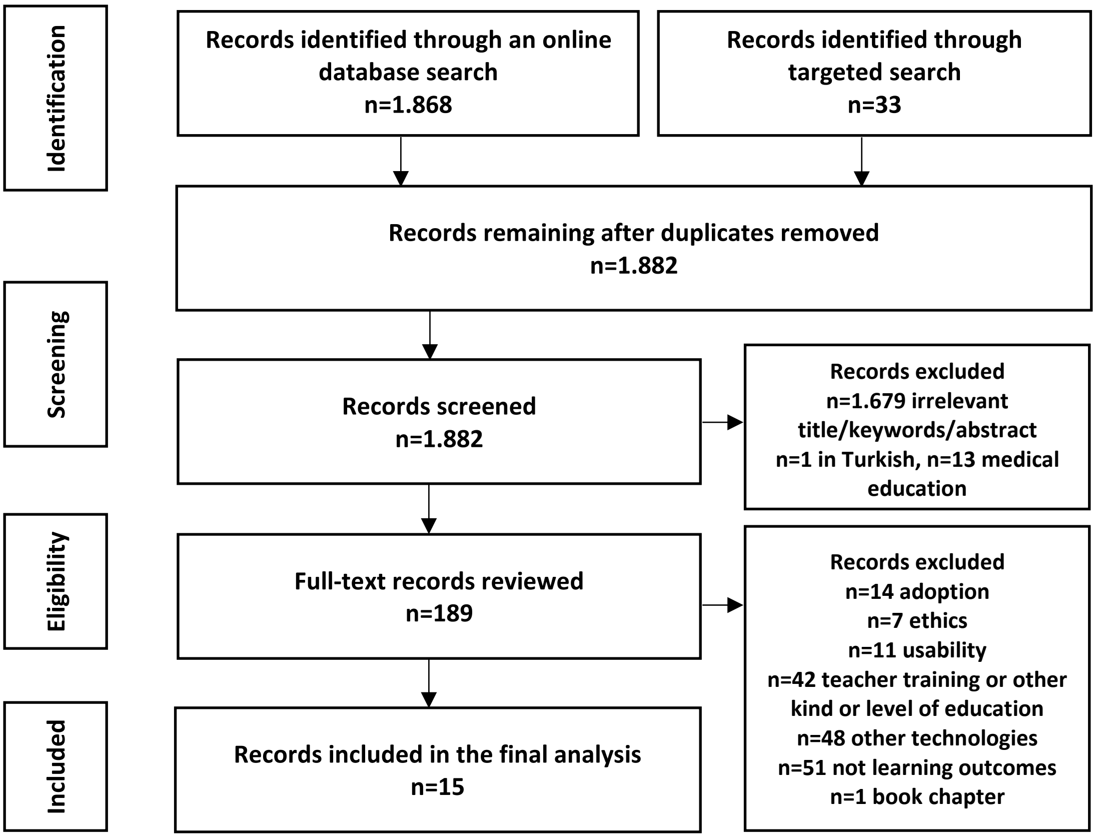

Figure 1. PRISMA flow diagram for the study (Moher et al., 2009)

Learning environment and subjects

Regarding learning environments, the literature review showed that the majority (Amin et al., 2015; Balestrini et al., 2014; Barker et al., 2015; Byun et al., 2018; Engen et al., 2017; Kuhn et al., 2016; Lee et al., 2016; Lindberg et al., 2016; Lukowizc et al., 2015; Merkouris et al., 2017) used wearable devices in a formal learning environment; namely, a school classroom. The subjects involved in these studies vary from Science to Linguistics and Physical Education. Specifically, two studies focus on Physics (Kuhn et al., 2016; Lukowizc et al., 2015) and another two refer to applied sciences; namely STEM (Barker et al., 2015) and Computer Science (Merkouris et al., 2017). One study focused on Statistics (Lee et al., 2016), and another one on Mathematics and Linguistics (Amin et al., 2015). Another study is related to Social Sciences, and, in particular, to a “Human Rights” activity (Balestrini et al., 2014). Also, Physical Education appears as the subject in two studies (Byun et al., 2018; Lindberg et al., 2016). Finally, one study (Engen et al., 2017) involves three subjects which are Mathematics, Social Sciences and Physical Education.

Three studies used wearable devices in non-formal learning environments, such as outdoors or around the school. More specifically, in the Chu and Garcia (2017) study, participants were tasked to record stories related to scientific concepts by using a smart watch when they were at school, or in a vehicle, or at home. Kerner and Goodyear (2017) asked 100 adolescents to wear a wearable fitness device for eight weeks. Adolescents used the Fitbit app to record their physical activity all day long. Garcia et al. (2018) conducted a five-week study with 18 fifth graders who recorded stories related to a science concept using a smart watch.

Table 1. Studies included in the literature review

Author/s	Aims Objectives	Device	Learning Environment	Subject	Level of Education	Learning Theories	Methodology: Type of Research	Methodology: Sample	Methodology: Data Collection Tools	Learning outcomes (performance, motivation, attitudes)
Amin et al. (2015)	To examine smart watches' impact on the development of basic linguistic abilities, shape recognition, and ability to tell time.	Smart watches	Formal environment (school)	Linguistics and Mathematics	Primary	Not mentioned	Experimental study	N=24 (5-6 years old), teachers and parents	Questionnaire, tests	The use of smart watches had a positive effect on students' academic performance and reinforced their interest in learning.
Balestrini et al. (2014)	If the use of SOS can facilitate collaborative activities resulting in greater enjoyment and better performance of the task as compared to a paper-based approach.	Wearable personal signal device (Arm bracelet)	Formal environment (school)	Social sciences (human rights)	Secondary	Not mentioned	Experimental study	N=52 (29 boys, 23 girls, 13-15 years old)	Observation, tests	Students who used the wristband spent significantly less time organizing the activity, achieved higher test scores, and experienced a stronger sense of group awareness.
Barker et al. (2015)	To examine the impact of wearable technologies intervention as a way to increase attitudes towards STEM.	E-textiles	Formal environment (school)	STEM	Primary/ Secondary	They refer to the constructivism theory along with PBL	Quasi-experimental study	N=21 (8-14 years old)	Pre and post surveys	Attitudes towards STEM were increased, but this was not statistically significant.

Author/s	Aims Objectives	Device	Learning Environment	Subject	Level of Education	Learning Theories	Methodology			Learning outcomes (performance, motivation, attitudes)
							Type of Research	Sample	Data Collection Tools	
Byun et al. (2018)	To assess the feasibility and efficacy of an intervention employing a wearable device and teacher-regulated techniques to foster pre-school physical activity.	Wearable fitness tracker devices	Formal environment (school)	Physical activity	Primary	The intervention was based on the social-ecological model and the health belief model	Quasi-experimental study	N=93 (average age 4,7 years old)	Software measurements questionnaires for parents	Children who used the wearable device showed a significantly lower level of sedentary behaviour and a higher level of total physical activity.
Chu & Garcia (2017)	To explore how smart watches can support informal science learning by recording out-of-school and everyday experiences related to science.	Smart watches	Non-formal environment (around the school, vehicle, home)	STEM	Primary	They mention Vygotsky's framework and situated learning theory	It is not mentioned	N=20 (12 boys and 8 girls, 8-11 years old)	Voice recordings from the smart watches, interviews with children	Students were able to utilize what they know about science and apply it to understand their surroundings. They had a sustained engagement with smart watches.
Engen et al. (2017)	If data collection could help in understanding abstract numbers and figures, and act as a motivational factor for learning mathematics and social science.	Smart watches	Formal environment (school)	Physical education, Mathematics, Social Sciences	Secondary	Not mentioned	Case study	N=21 (8 girls and 13 boys, 13-14 years old)	Observation, interview with the teacher	Wearable technology was motivational for the pupils. Their use in teaching offered opportunities for pedagogy in and around subjects like mathematics and social sciences.

Author/s	Aims Objectives	Device	Learning Environment	Subject	Level of Education	Learning Theories	Methodology			Learning outcomes (performance, motivation, attitudes)
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Garcia et al. (2018)	To present an approach to commodity smart watches as a tool for situated reflection in primary school science.	Smart watches	Non-formal environment (around the school, home)	Science	Primary	Reference of the Theory of Situated Cognition	A nested design, whereby the top-level factors were 'intervention' and 'baseline'	N=18 (7 boys, 11 girls, average age 10,5 years old)	Questionnaire, interview, recordings from the smart watches	The use of the smartwatch as a situated reflection tool has positively affected students' self-efficacy in science.
Kerner & Goodyear (2017)	To examine whether a wearable fitness device can affect physical activity motivation for adolescents by providing them with greater satisfaction and self-determined motivation.	Wearable fitness device	Non-formal environment (around the school, home)	Physical education	Secondary	They refer to self-determination theory as a framework in the study of physical activity	Mixed method sequential design	N=84 (44 girls, 40 boys, 13-14 years old)	Questionnaire, focus group interviews	The impact of a wearable fitness device on adolescents' motivation, attitudes and perceptions was negative
Kuhn et al. (2016)	How Google Glass can be used as an experimental tool for wearable-technology-enhanced and inquiry-based learning in physics education.	Smart Glasses	Formal environment (school)	Physics experiments (acoustics)	Secondary	Cognitive theories (Cognitive Theory of Multimedia Learning, Cognitive Load Theory)	Experimental study	N=46 (16 girls, 30 boys of 8th grade)	Log files from the Google Glass app, pretests and post measures (questionnaires)	Google Glass foster curiosity and wondering. There was a positive trend for experimentation. No difference in students' learning and cognitive load between Google Glass and tablets.

Author/s	Aims Objectives	Device	Learning Environment	Subject	Level of Education	Learning Theories	Methodology			Learning outcomes (performance, motivation, attitudes)
							Type of Research	Sample	Data Collection Tools	
Lee et al. (2016)	How a wearable that tracks physical activity, when used in elementary statistics classes, could produce authentic and detailed data on activities and experiences already known to students.	Wearable fitness activity tracking device	Formal environment (school)	Statistics	Primary	Not mentioned	Quasi-experimental study	N=18 (10-11 years old)	Questionnaire, observation	Improvement in specific statistics conceptions was detected. There was no significant difference in performance between the group that used the smart watches and the control group.
Lindberg et al. (2016)	To examine whether wearable technology exergames can enhance learning, exercise and motivation in PE classes.	Smart watches	Formal environment (school)	Physical Education	Primary	Not mentioned	Experimental study	N= 61 (32 boys, 28 girls, in one case sex was not reported)	Questionnaire, quiz, interview with the teacher	Learning with exergames in combination with wearable technology was more efficient, and students were engaged as players.
Lukowicz et al. (2015)	How Smart Glasses can minimize the effort involved in performing high school physics experiments.	Smart Glasses	Formal environment (school)	Science	Secondary	Not mentioned	Experimental study	N=36 (17-18 years old)	Questionnaire	Smart Glasses reduced the effort in conducting high school physics experiments. The experimental group performed better than the control group in terms of cognitive load and curiosity.

Author/s	Aims Objectives	Device	Learning Environment	Subject	Level of Education	Learning Theories	Methodology: Type of Research	Methodology: Sample	Methodology: Data Collection Tools	Learning outcomes (performance, motivation, attitudes)
Merkouris et al. (2017)	To compare which device (desktop, wearable, robot) is more suitable to be used as a target platform for learning to program in computer code.	A messenger bag of LEDs (Arduino LilyPad platform)	Formal environment (school)	Programming	Secondary	Reference of the constructionist learning theory	Experimental study	N=36 (18 girls, 18 boys, 12-13 years old)	Questionnaire, tests	The wearable platform did not affect the students' performance. No significant treatment was observed between the wearable treatment and the generic one.
Nugent et al. (2019)	To measure the impact of wearable technology on students' knowledge of circuitry, programming, and engineering design, and self-efficacy in producing a wearable e-textile product.	Wearable textiles	Formal environment (school) and non-formal environment (after-school)	STEM	Primary	According to the authors, the use of wearable textiles in education is related to constructivism and to Papert's constructionist extension.	Quasi-experimental	N=1425 (687 girls, 738 boys)	Pre and post instruments for students, post-project interviews with teachers	Both formal and non-formal instructional settings resulted in significantly higher scores in student knowledge of programming and circuitry, as well as STEM self-efficacy, compared to the control group.
Shadiev et al. (2018)	To examine the potential of a learning activity to teach English combined with exercise, supported by smartwatches.	Smart watches	Formal environment (school) and non-formal environment (outside of the school)	English	Secondary	Not mentioned	Experimental study	N=18 (9 boys and 9 girls of 14-15 years old)	Questionnaire survey, interviews with students	Students performed best on learning tasks when using smart watches. They also developed positive emotions for the English class and wearable devices.

The recordings were conducted at the children's school and homes, and were related to their daily lives. Two of the studies combined formal and non-formal learning environments. The first was conducted by Shadiev et al. (2018), where students participated in a learning activity that was supported by a smart watch. The researchers divided the learning activities into indoor and outdoor settings. These learning activities referred to English as a foreign language. The second was conducted by Nugent et al. (2019), which also combined formal and non-formal learning environments by dividing the participating students into two groups. The subject involved was STEM. A teacher instructed one group in a formal setting, and the other group was instructed by a teacher in a non-formal setting - in this case, an after-school environment.

Education level

In terms of education level, the literature review showed that there is an equal interest among researchers concerning primary and secondary education. Specifically, in one of the studies, participants were preschoolers (Byun et al., 2018), in six of them, the participants were primary school students (Amin et al., 2015; Chu & Garcia, 2017; Garcia et al., 2018; Lee et al., 2016; Lindberg et al., Nugent et al., 2019). Another seven studies were found whose participants were either middle or high school students (Balestrini et al., 2014; Engen et al., 2017; Kerner & Goodyear, 2017; Kuhn et al., 2016; Lukowicz et al., 2015; Merkouris et al., 2017; Shadiev et al., 2018). One of the studies involved a mixed population of participants from primary and secondary schools (Barker et al., 2015).

Learning theories

Seven of the studies do not refer to any learning theory or other pedagogical background. In six of the studies, the authors mention the learning theory that they apply. Nugent et al. (2019) relied on the constructivism theory of learning and Papert's constructionist theory, along with problem-based learning theory (PBL) when using e-textiles in their study. Barker et al. (2015) apply constructivism and PBL as their learning theory and learning model, respectively, in their study as well. Kuhn et al. (2016) refer to specific cognitive theories, such as the Cognitive Theory of Multimedia Learning and Cognitive Load Theory, to frame their study, which is related to the use of smart glasses in an acoustic experiment. Garcia et al. (2018) mention the Situated Learning Theory to ground their study, which is related to the use of a smart watch app called "ScienceStories". Chu and Garcia (2017) also relate the students' everyday experiences, as captured in the stories that they record, to Situated Learning Theory, Embodied Cognition, and Vygotsky's framework. Finally, although Merkouris et al. (2017) mention that the use of Lego Mindstorms, which are part of their study, are related to the constructionism learning theory, they do not ground the use of wearables in any learning theory.

Two studies apply specific models or frameworks as part of their theoretical background, but these models or frameworks are not related to any learning theory. More specifically, Kerner and Goodyear (2017) use self-determination theory, a theory related to physical activity, to ground the theoretical framework of their study. Byun et al. (2018) develop their intervention based on the Social Ecological Model and the Health Belief Model.

Methodological design

In terms of the methodological design, the current review examined the research design, the data collection tools, the type of research that researchers conducted and the sample that they used. Most of the reviewed studies used both quantitative and qualitative research design (Balestrini et al., 2014; Garcia et al., 2018; Lee et al., 2016; Lindberg et al., 2016; Kerner & Goodyear, 2017; Nugent et al., 2019; Shadiev et al., 2018), followed by those that used a quantitative design (Amin et al., 2015; Barker et al., 2015; Byun et al., 2018; Kuhn et al., 2016; Lukowicz et al., 2015; Merkouris et al., 2017). Two studies are based on a qualitative research method (Chu & Garcia, 2017; Engen et al., 2017).

The majority of the research was based on experimental or quasi-experimental studies utilizing an experimental group for the use of wearable devices and a control group to compare the results to traditional teaching or other devices (Amin et al., 2015; Balestrini et al., 2014; Barker et al., 2015; Byun et al., 2018; Kerner & Goodyear, 2017; Kuhn et al., 2016; Lee et al., 2016; Lindberg et al., 2016; Lukowicz et al., 2015; Merkouris et al., 2017; Nugent et al., 2019; Shadiev et al., 2018). One of them is a case study (Engen et al., 2017). Also, it is worth mentioning that in one case the type of research was not mentioned (Chu & Garcia, 2017).

Regarding the data collection tools, researchers utilized a variety of quantitative and qualitative tools. The quantitative data collection tools can be divided into the following categories: (a) questionnaires (e.g., Lee et al., 2016), tests (e.g., Amin et al., 2015) and quizzes (e.g., Lindberg et al., 2016), and (b) data recorded from log files (e.g., Kuhn et al., 2016) or software measurements (e.g., Byun et al., 2018). The qualitative data collection tools can be divided into the following categories: (a) interviews (e.g., Shadiev et al., 2018) or focus group interviews (e.g., Kerner & Goodyear, 2017), (b) observation (e.g., Engen et al., 2017), and (c) data recorded from the devices (Chu & Garcia, 2017). The literature review also revealed that in some cases researchers used a convenience sample (Amin et al., 2015; Balestrini et al., 2014; Barker et al., 2015; Lee et al., 2016; Lindberg et al., 2016; Lukowicz et al., 2015; Chu & Garcia, 2017; Kerner & Goodyear, 2017; Garcia et al., 2018; Shadiev et al., 2018).

Learning outcomes

In terms of learning outcomes, the current review examined the impact on learning performance, learning motivation, and learning attitudes and perceptions. As previous systematic reviews (i.e., Haßler, Major & Hennessy, 2016; Nikou & Economides, 2018; Acquah & Katz, 2019) of the evidence for learning outcomes (when using mobile technologies or computer) have done, the impact is described as positive (meaning improvement or increase), negative (meaning decrease), neutral (meaning no significant impact), mixed (meaning positive for one part of the study and neutral for another) or not measured. Table 2 summarizes the findings about the impact of smart wearables on performance, motivation and attitudes/perceptions (see also Table 1).

According to Table 2, a group of five studies explored the impact of wearables on both performance and motivation. Specifically, the results of the Amin et al. (2015) study showed a better performance within the experimental group that used the smart watch to develop language skills, as well as pattern recognition and time learning. Also, they report that parents of students from the experimental group said that their children showed particular interest and enthusiasm for learning through smart watches.

Table 2. Impact of smart wearables on learning outcomes

Author/s	Impact on performance	Impact on motivation	Impact on attitudes/perceptions
Balestrini et al. (2014)	positive	not measured	positive
Amin et al. (2015)	positive	positive	not measured
Barker et al. (2015)	not measured	not measured	positive
Lukowicz et al. (2015)	positive	positive	not measured
Kuhn et al. (2016)	neutral	positive	not measured
Lee et al. (2016)	mixed	not measured	not measured
Lindberg et al. (2016)	positive	positive	not measured
Chu & Garcia (2017)	positive	positive	not measured
Engen et al. (2017)	not measured	positive	not measured
Kerner & Goodyear (2017)	not measured	negative	negative
Merkouris et al. (2017)	neutral	neutral	neutral
Byun et al. (2018)	positive	not measured	not measured
Garcia et al. (2018)	not measured	not measured	Positive
Shadiev et al. (2018)	positive	not measured	positive
Nugent et al. (2019)	mixed	not measured	positive

Lukowicz et al. (2015), who split students into two groups - an experimental group using Google's glasses and an established tablet-based control group - found a statistically important difference between the two groups. The experimental group performed better than the control group in execution, cognitive load, and curiosity. Kuhn et al. (2016) found no significant impact on learning performance and positive impact on motivation. In particular, they found that the use of Google Glass in acoustic experiments did not affect students' learning achievement. This result is attributed by researchers to the technical limitations of Google Glass at the time (e.g., processing speed and quality of the camera). On the other hand, they found that learning with smart glasses promotes curiosity and wonder. The results of the Lindberg et al. (2016) experimental study showed that learning with smart watches while playing the game "Exergame Running Othello 2" was more effective, players became more engaged in the game, and players' fitness improved. Chu and Garcia (2017) found that that the use of smart watches to capture science stories was successful as students recorded five story types (e.g., accounts of personal experiences or observations of habits) and adopted five types of roles (e.g., observer or actor). They also found that the stories were indeed related to science in three ways (e.g., the story emphasized a characteristic or form related to a scientific concept). In addition, in terms of informal science learning, they found that students were able to utilize what they know about science and apply it to understand the world around them. Regarding students' motivation, the researchers noted that students who used a smart watch to capture science-related stories exhibited sustained engagement. This is attributed to the fact that each child recorded four to five stories on average over two days.

Another group of three studies investigated the impact of smart wearables both on performance, as well as attitudes and perceptions. The Balestrini et al. (2015) research showed that students who used an arm bracelet spent less time planning the task, received better scores, reported a greater sense of knowledge of group composition, and liked the overall activity substantially more than their classmates in the control group. Shadiev et al. (2018) found that students performed the best on learning tasks when using smart watches. Also, they developed positive emotions towards English class and wearable devices. Moreover, the results showed a statistically significant association between students' learning performance and physical activity, which suggests that students who performed more physical activity were the ones who showed better performance in learning. On the other hand, Nugent et al. (2019) presented mixed results regarding the impact on performance. They found that their intervention based on wearable textiles resulted in higher scores in student programming and circuitry awareness but no significant difference in knowledge of engineering design in both formal and informal environments. However, their findings on the impact on attitudes and perceptions indicated a positive trend. In that case, they found that in both formal and informal educational environments the designing of a wearable e-textile product resulted in significantly higher scores of STEM self-efficacy in comparison to the control group.

Another two studies investigated the impact of smart wearables on students' attitudes and perceptions. In particular, Barker et al. (2015) measured students' attitudes towards STEM with eight variables that were related to motivation, self-esteem, and learning strategies by performing a wearable electronics intervention. Researchers found that attitudes of students increased after this intervention, but there was no statistically significant difference compared to pre-intervention attitudes. The quantitative results of the Garcia et al. (2018) study showed that the smart watch application "ScienceStories" increased students' self-efficacy for Science. The version of the smart watch application with elements of gaming had the greatest impact. In contrast, the one with the narrative elements had the least impact. Kerner and Goodyear (2017), who measured the impact of a wearable fitness device on adolescents' motivation, as well as attitudes and perceptions, presented negative results in both cases. They noted that competition with peers may explain this negative result, because this kind of competition creates negative feelings, such as guilt.

Their findings indicated that participants presented decreased competence, autonomy, and relatedness to peers, as well as reduced autonomy motivation, while their amotivation increased.

Merkouris et al. (2017) investigated the impact of a wearable platform (Arduino LilyPad platform) on students' performance, motivation, as well as attitudes and perceptions. In all cases, their findings revealed neutral results. More specifically, they found that the wearable platform did not affect students' performance in learning basic computational concepts. They attribute this result to the brief (one hour) intervention which might not have been enough for students to fully understand programming knowledge. They also found that the impact on motivation, as well as attitudes and perceptions was not significant. They attribute this result to the type of wearable used in their research, which was the Arduino LilyPad platform. They explain that it is not the most sophisticated one so it might have affected students' emotional engagement.

Other studies investigated either the impact of smart wearables on performance, motivation, or attitudes and perceptions. For instance, Lee et al. (2016), who presented mixed results on the impact of smart watches on learning performance. On the one hand, they found that the use of a smart watch in Statistics resulted in improvement in specific conceptions, such as the Conception of Statistics, Data Display, and Informal Inference. On the other hand, they found no significant difference in terms of MetaRepresentational Competence or Modeling Variability. Engen et al. (2017) explored the impact of smart watches on students' motivation for learning Mathematics and Social Sciences. Data collection from smart watches during Physical Education class was conducted by students themselves. The findings of the research showed that motivation for learning increased for Physical Education and Mathematics. Byun et al. (2018), who implemented an intervention that employed a wearable fitness tracker to promote physical activity in preschoolers, hypothesized that children's physical activity levels would be greater when compared with those who did not take part in the intervention. Indeed, children from the intervention group, whose activity was tracked in real-time through the fitness tracker, demonstrated substantially lower sedentary behaviour rates and a higher degree of overall physical activity.

Factors that affect the use of smart wearables in education

Seven out of the 15 reviewed studies refer to factors that affected the use of wearables when used in their research. An important factor affecting the use of wearable technologies in education is the collection of students' sensitive personal data (e.g., height, weight, pulse, photos, videos, location). Engen et al. (2017) highlight this problem in their research. To avoid any stigmatization problems related to the students' height and weight, they adjusted the smart watches being used to have the average height and weight of boys and girls 14 years of age as set by the Norwegian Statistical Service. To avoid collecting data on students' locations during their free time, the researchers decided to restrict the use of smart watches only to the school premises. They also assigned a code for each smart watch. They asked each student to use it, without the researchers knowing to which student each device code corresponded.

Another factor that affects the use of wearable technologies in education is the financial aspect. Amin et al. (2015) explain that one reason for using a small-sized sample was the fact that the school administration provided a small number of gadgets. Other researchers focus on technical and design issues associated with wearables' hardware and software. Kuhn et al. (2016) point out that the technological limitations of the Google Glass device, such as its processing speed and the quality of the camera, may have affected the results of their study. Garcia et al. (2018), who designed and developed three versions of a smart watch application (gamified, narrative-based, and hybrid), report that the type of application being used affected students' involvement with the device. Specifically, they found that the gamified version of the smart watch application led students to generate sufficient recordings of stories related to a science concept, in contrast to the other two versions of the application.

On the other hand, Shadiev et al. (2018) refer to the factor of time. Time restrictions led students that participated in their study to use smart watches for a short period. According to the researchers, that limitation may have influenced the results of the research. Time restriction is also a factor that might have hampered students' creativity and full involvement with the wearables (Arduino Lily Pad platform), according to Merkouris et al. (2017). Finally, in their study, Lindberg et al. (2016) cite a list of factors that influence the use of wearable technologies. According to the interviewed teacher who participated in the study, these factors are cost, maintenance, storage, teacher training, and material preparation for educational activities.

Discussion

This literature review aimed to examine existing research regarding smart wearables in primary and secondary education, identify research gaps, and recommend future research. This review includes studies published between 2010 and 2020 that involve primary and secondary education. The inclusion criteria for this review resulted in 15 studies, the results of which were presented in terms of the device utilized, learning environment, subject, level of education, learning theories, research methodology, learning outcomes, and factors affecting the use of smart wearables in education.

The first research question aimed to examine the smart wearables that were used in studies. Our review revealed that smart watches and fitness trackers were the devices of choice in the majority of studies. This finding is in line with previous literature reviews which show that smart watches and fitness trackers are the devices that are used most frequently in various studies (e.g., Kirk et al., 2019; Koumpouros & Kafazis, 2019). It is also interesting to note that, in the current review, only two studies referenced the use of smart glasses. One might expect that smart glasses would be more frequently used in the papers studied, as they are a new trend able to offer new virtual, augmented and mixed reality experiences. This result contradicts research on the use of smart wearables in medical education, where smart glasses such as Google Glass is used in the majority of studies (Kolodzey et al., 2016).

The second research question focused on the learning environments as well as on the subjects in which smart wearables were used. Most of the studies in this literature review were conducted in classroom settings. Furthermore, of the 15 studies included in the review, a large number of them investigated the use of smart wearables in Mathematics/Statistics, Physics, and STEM. In regards to the third research question, of the 15 studies, 7 were conducted at the primary education level, 7 at the secondary education level, while one was conducted at both levels. Based on the current review study, it is difficult to relate these results to students΄ learning outcomes. Therefore, more research is needed to explain how smart wearables influence students΄ learning in different learning environments, subjects and level of education.

The fourth research question explored the studies' pedagogical framework. It was found that some studies lacked a pedagogical framework stemming from learning theories. Other reviews also found that studies in wearable technologies lack theoretical foundation (Niknejad et al., 2020; Girginov et al., 2020). Furthermore, this result is in line with previous reviews regarding the use of other technological novelties in primary, secondary or higher education. For instance, Zhang and Nouri (2018), who reviewed 39 empirical studies on the use of tablets in learning and teaching in formal education at primary and secondary schools, also found that only a few of the studies based their learning and teaching activities on learning theories. More recently, Radianti, Majchrzak, Fromm and Wohlgenannt (2020) reviewed 38 articles from 2016 to 2018 on immersive virtual reality applications for higher education and found that very few of them based their VR applications on a specific learning theory.

The fifth research question was formulated to examine the research methodology used in studies on smart wearables. Most of the reviewed studies used both quantitative and qualitative research design, followed by those that used a quantitative design. In addition, the majority of the research was based on the experimental or quasi-experimental study design. Most of the papers utilized a combination of different quantitative and qualitative data collection tools in order to assess the impact of smart wearables in students' learning. Also, it is worth mentioning that the aim of this review was not merely to report the methodology used in the studies, but also to identify their methodological limitations. By finding these studies' limitations, we can conduct future studies with greater methodological rigor. A common methodological approach was adopted from previous literature review studies (e.g., Koumpouros & Kafazis, 2019). In this regard, it was found that one study does not mention the type of research employed. Furthermore, it was found that some studies used a convenience sample. In addition, it was found that none of the studies was longitudinal.

The sixth research question aimed to determine the main learning outcomes measured by smart wearable studies. In this regard, it was found that in many cases there are several learning outcomes from using smart wearables in education, such as improved performance, increased motivation, and attitudes towards learning. More specifically, positive outcomes on learning performance were associated with smart watches (Amin et al., 2015; Chu & Garcia, 2017; Lindberg et al., 2016; Shadiev et al., 2018), smart glasses (Lukowicz et al., 2015), the arm bracelet (Balestrini et al., 2014), and the fitness tracker (Byun et al., 2018). These positive learning outcomes were about learning activities related to a variety of subjects, such as Social Sciences (Balestrini et al., 2014), Linguistics and Mathematics (Amin et al., 2015), Science (Lukowicz et al., 2015), STEM (Chu & Garcia, 2017), Physical Activity (Lindberg et al., 2016; Byun et al., 2018) and English as a foreign language (Shadiev et al., 2018). Furthermore, positive outcomes on students' motivation and attitudes included, among other things, interest in learning, fostering curiosity and wondering, engagement, enjoyment, increased self-efficacy, and positive emotions towards a subject. However, in two cases smart technology did not influence students' performance, motivation, or attitudes. In both cases, this was attributed by researchers to the technical characteristics of wearable devices used in their studies. Kuhn et al. (2016) refer to specific technical limitations of Google Glass (e.g., processing speed and quality of the camera) and Merkouris et al. (2017) refer to the fact that Arduino LilyPad is not the most refined technology. In one case (Kerner & Goodyear, 2017), negative results were reported on the impact of a fitness tracker on adolescents' motivation and attitudes towards physical activity. This is because participants, when using the fitness tracker to record their physical activity, felt like they were taking part in a competition with their peers, resulting in negative emotions.

The final research question was formulated to examine the factors that influence the use of smart wearables. In this regard, the following factors emerged from the literature: the students' sensitive personal data, the financial aspect, technical and design issues, lack of time, and teacher training. Factors such as these have been found to affect the use of ICT in education up until recently (e.g., Gil-Flores, Rodríguez-Santero & Torres-Gordillo, 2017). In terms of technical issues, today's 5G networks provide high reliability (Geršak et al., 2020), therefore issues related to smart wearables' internet connection will significantly decrease.

Limitations of the review

This review has some limitations. One limitation is that only papers published in journals and conference proceedings available through the authors' institutional library were considered. Articles to which the authors did not have open access were excluded from the review. Their inclusion into this review may likely have altered the results. Another limitation is that this review used specific databases. There might be other databases which may be able to provide a better picture of the articles related to smart wearables in education.

Conclusions

This literature review summarizes evidence from 15 studies of smart wearables in primary and secondary education published between 2010 and 2020. Our literature review shows that the existing research on the use of smart wearables in education, compared to research conducted in the field of medicine and physical activity, is still in its early phase. Most specifically, little is known about the affordances of devices that impact students' learning. Current research has focused mostly on devices such as smart watches and fitness trackers. In addition, none of the studies compared different wearable devices and their effects in learning. Similarly, the effect of smart wearables in informal learning environments such as museums and archaeological sites have not yet received the attention needed to draw any conclusions on their impact on students′ learning.

The review also showed that only about half of the studies were based on a theory of learning. The lack of a pedagogical framework does not help us to understand the way in which wearable technologies are used and how students interact with them. This review also identified that there were a few methodological concerns that arose in studies on smart wearables. First, a number of studies used a convenience sample, and second, one study does not mention the type of research used. Future studies should move beyond these limited methodological issues. Furthermore, the literature review identified several outcomes of using smart wearables in learning, such as improved student-motivation and attitudes, interest in learning, fostering curiosity and wondering, engagement, enjoyment, increased self-efficacy, and positive emotions towards a subject. Although this review provides evidence regarding the positive effect of smart wearables on students' learning, this review also demonstrates that research into such effects has only just started. More findings are needed in order to correlate this effect with variables such as the type of device, learning environment, subject, and learning theory. Finally, factors that seem to affect the use of smart wearables are students' sensitive personal data, the financial aspect, technical and design issues, lack of time and teacher training.

To the best of the authors' knowledge, this is the first literature review on smart wearables in primary and secondary education. The results of this review study provide insights into the current state of smart wearables in primary and secondary education and offer a future research agenda for smart wearables in teaching and learning.

Future research

According to the recent data, the number of smart wearables will continue to grow (for example, see Statistica, 2019; 2020). Due to the continual decrease in their cost (e.g., smart watches) and the technological advantages they will incorporate, their use is expected to be widely adopted by the new generation, as was precisely the case with smartphones in previous years. The present literature review showed that the existing research on the use of smart wearables in education is still in the beginning stages. More research is needed that will focus on the issues presented in a previous section. Specifically, the aim is for smart wearables to be not just a passing trend in education, but rather, to serve as an opportunity for the education and research community to showcase these devices' added value regarding actively engaging students and their ability to connect experiences from informal and formal learning environments. More specifically, the challenge remains for researchers to examine the degree to which the experiences gained by students from the use of smart wearables in informal learning environments (e.g., student visits to museums, activities in outdoor areas that possess a particular historical and cultural value) can be used in the learning process to contribute to increased motivation toward learning, the promotion of cooperation and the development of 21st century skills.

Within this framework, the research and education community is called upon to resolve issues related to the protection of data being collected, the types of educational applications that the devices will feature, the pedagogical framework in which they will be used, and mainly, the type of training needed by teachers to integrate them into their instruction. The point of the pedagogical framework is to form the appropriate learning conditions allowing students to be not just passive users of wearable devices, but rather, to utilize them as a research tool that can be used to help them construct knowledge. From this standpoint, it would be interesting to see studies conducted that will utilize learning theories favoring authentic, constructivist, and situated learning. In general, since smart wearables are paired and exchange data with mobile devices (i.e., smartphones and tablets), and also possess similar capabilities (e.g., mobility, internet connection), they can be studied under the pedagogical framework that applies to mobile learning. In addition, new digital literacies that are emerging through the use of various smart wearables must be studied. Moreover, new instruments to measure the different experiences gained by students from their use (i.e., using smart glasses to view augmented reality) need to be developed. Finally, smart wearables need to be studied in terms of their ability to utilize the learning opportunities arising from the evolution of the Internet of things and the emergence of new technologies (e.g., drones, augmented and mixed reality, 3D printing).

In conclusion, future research should be enriched with more methodological rigor and longitudinal studies to answer the following questions: (a) What smart wearables and which of their features can produce a positive impact on learning? (b) Under what specific pedagogical framework can this be achieved? (c) To which subjects in the curriculum could smart wearables most contribute when compared to current/traditional teaching methods or already existing ICT applications? (d) How can smart wearables be utilized in informal learning environments and in what types of activities can students be engaged? (e) How can smart wearables and mobile devices (e.g., smart phones) be used together to promote learning?

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