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CATCHWORD

Digital Therapeutics (DTx)

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1 Digital Therapeutics (DTx): Apps on Prescription

Apart from researching large-scale infrastructural technologies like electronic health records and health information exchanges, the field of healthcare IT is increasingly interested in exploring how individuals can play a more active role in their healthcare journeys (Baird et al. 2020). Digital Therapeutics is a prime example of this trend, occupying an intriguing conceptual position between consumer-grade mobile apps and wearables on one end and safety- and quality-controlled Software as a Medical Device on the other end.

Digital Therapeutics (DTx) can be defined as *therapeutic interventions through a clinically evaluated, patient-directed*[1] *software application intended to improve the process of diagnosing, treating, managing, and/or preventing diseases*. For instance, the pharma company Boehringer Ingelheim and Click Therapeutics announced to develop a DTx to aid treating schizophrenia (Ruckel 2020). New regulatory frameworks were introduced in the United States, Asia, and several European countries. With those, DTx are becoming a new pillar in providing care to patients–beyond the traditional ambulatory and clinical healthcare.

In Europe, Germany has set an example. DTx entered universal reimbursement in 2019 under the label *DiGAs* (Digitale Gesundheitsanwendungen [Digital Health Applications]; BMG 2020). This made it one of several European countries[2] implementing a reimbursement pathway for DTx for universal coverage by health insurances (Gerke et al. 2020; Brinkmann-Sass et al. 2020). Therefore, it advanced a definition and regulatory framework for DTx. As outlined by Gerke et al. (2020), this development shows a broader shift in how healthcare is delivered with the support of digital technologies, in the case of Germany following a primarily market-oriented approach.[3] Other

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[1] Including those whose primary purpose is directed towards patients and that entail both patients and therapists.

[2] European countries are currently working out own regulatory frameworks, the European Medicines Agency has not yet designed a regulatory pathway for evaluation and reimbursement of DTx.

[3] Denmark and other Nordic countries are taking a coordinated approach by stepwise integrating other main aspects of health care digitalization like electronic health records and platforms implementing mobile apps along the process (Nordic Innovation 2018).

European countries like the UK, Belgium, Latvia (Baltic Times 2021), or France, and Asian countries such as Japan, Korea, and China (Hong et al. 2021) are taking steps in such a direction; Belgium is adopting the path Germany has set as an insurance-based country (Brown 2021). In contrast, in the UK, the National Health Service (NHS) is funding the development of DTx and offers universal reimbursement (Myler 2020). The Food and Drug Administration (FDA) in the US has also made first steps in clearing DTx for reimbursement using the term Prescription Digital Therapeutics (PDTs) (Patel and Butte 2020). The Digital Therapeutics Alliance (DTA), a non-profit trade association of industry stakeholders engaged in the field of DTx, has compiled regulatory processes for each country (DTA 2022). These developments have brought a special focus and acceleration to DTx, impacting care processes for different stakeholders and opening new markets.

Where as many people have installed genuine medical applications on their smartphones for the first time in recent years, introducing DTx into public healthcare systems can also provide the opportunity to reorganize and steer scarce health care resources. Thus, it adds a possibly cost-effective intervention strategy of controlled quality following regulatory standards that can help to lower the barriers for so far unreached or excluded groups or regions with inadequate health care infrastructure. As such, it represents a possibility to change care processes and interfaces with traditional healthcare IT such as electronic health records, on an individual, but also on a population and community level. This is in line with a previously observed shift away from patients as passive recipients of healthcare services towards a more active and empowered role of the patient in shaping his or her treatment process (Baird et al. 2020), it also brings possibilities for a personalized, preventive, and predictive care journey.

In this catchword, we delineate the concept of DTx, providing a definition framework based on which areas of research are outlined for Business and Information Systems (BISE) scholars. We argue the case for the importance of DTx in opening up areas of interest on an individual/micro and macro/societal level regarding the dimensions of data, technology, social process integration, and value (DTxSV)–outlining a DTxSV research framework specific to DTx.

2 Delineating the DTx Concept

DTx can be regarded as a subset of Software as a Medical Device (SaMD) and are often related to Mobile Health (mHealth) (Fig. 1). While BISE/IS research on Healthcare Information Technology has traditionally focused on large-scale infrastructural technologies, such as Electronic Health Records (EHRs, Hoyt and Hersh 2018) and Health Information Exchanges (Yaraghi et al. 2015), developments in SaMD (FDA 2019) have led to the stronger realization that software may be used for explicit medical purposes, and advancements in mHealth (Steinhubl et al. 2013) have resulted in a more in-depth consideration of patient empowerment and patient-generated health data (Nittas et al. 2019). In the following, the DTx concept will be discussed in relation to the two concepts of SaMD and mHealth, whereby we consider regulatory, technological, and medical purpose aspects. We refer to medical purposes as processes of diagnosing, treating, managing, and/or preventing diseases, and we consider scenarios in which health care professionals and/or patients are involved in (mobile) interventions.

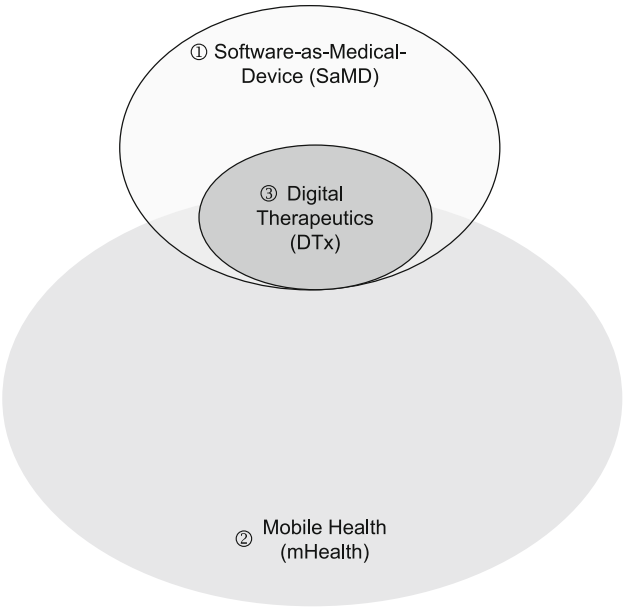

Fig. 1 Delineating ①SaMD and ②mHealth from ③DTx

The term "Software as a Medical Device" (SaMD) (①) has been defined by the International Medical Device Regulators Forum as software intended to be used for one or more medical purpose(s) that perform(s) these purposes without being part of a hardware medical device (IMDRF 2013). Software that falls under this definition thus *is* considered as a medical device according to the Medical Device Regulations (MDRs) in Europe, or by the FDA in the US, or other regulatory bodies elsewhere. Such software is capable of running on general-purpose (non-medical purpose) computing platforms. Here, "without being part" means that software does not need a hardware medical device to function, whereas software does not meet the definition of SaMD if its intended purpose is to drive a hardware medical device. SaMD may be used in combination (e.g., as a module) with other products, including

medical devices, and may be interfaced with other medical devices, including hardware medical devices and other SaMD software, and general-purpose software. One example is radiological computer-assisted diagnostic software for lesions suspicious for cancer, which helps radiologists to classify images based on AI algorithms (FDA 2020). DTx can always be considered SaMD, but mostly exclude the purpose of primary prevention (no diagnosed illness given, e.g., general health apps).

A part of the DTx applied via a mobile technology can fall within the broad term *Mobile Health (mHealth)* (②). The Global Observatory for eHealth (GOe) by the WHO defined mHealth as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (WHO 2011). At the point of time of writing, there are 41,517 mobile apps with a broad focus on "digital" or "mHealth" available in the Apple App Store (Statista 2022). The FDA (2019) considers a "mobile app" as a software application that can be run on a mobile platform (a handheld commercial off-the-shelf computing platform, with or without wireless connectivity), or a web-based software application that is tailored to a mobile platform but is executed on a server. Among the mHealth apps, many are focusing on more general health objectives, for instance, general health or wellness purposes, such as delivering training videos, meditation, or, for instance, monitoring caloric intake for healthy weight maintenance. For example, the NIH's LactMed app provides nursing mothers with information about the effects of medicines on breast milk and nursing infants. mHealth is a term that can contain many DTx but also other mobile-enabled technologies focusing on more general health purposes (primary prevention) and solutions that are not clinically evaluated, not as highly regulated, and not reimbursed in the public healthcare system. Currently, mobile applications are one key interface for DTx, but DTx can also be delivered by non-mobile technologies.

When considering the intersection of mHealth and SaMD (① ∩ ②), it is important to note that some mHealth apps may fall under the classification of SaMD if they are designed to perform medical functions and operate independently of a hardware medical device. However, it is important to differentiate these SaMDs[4] from DTx. DTx, not exclusively, but in many countries, are considered patient-directed or must address patients professionals, but not only professionals. This means that apps that are only used by the physician to treat the patient are not considered as DTx. On a regulatory level, there are further differences, for instance, in how far the purpose of *diagnosing* is included.[5]

In the light of the preceding considerations, DTx (③) are referred to as *therapeutic interventions through a clinically evaluated, patient-directed software application intended to improve diagnosing, treating, managing, and/or preventing diseases*. The definition implies different dimensions along which DTx can be delineated. (1) The **medical purpose** is specific to a medical condition and does not address more general health purposes. (2) Since defined as a **therapeutic intervention**, in contrast to the multitude of mHealth apps, they have an own mechanism of action through which the medical purpose is fulfilled, e.g., providing CBT-based VR-exposition training, and (3) DTx are held to similar standards as prescription drugs or other medical devices in terms of **clinical evaluation** (i.e., efficacy, safety, and quality) through regulatory oversight are applied. Like medications, DTx are approved by regulatory bodies (such as FDA or BfArM) after enough clinical evidence is presented. (4) DTx are based on **software applications** and therefore are a form of Software as a Medical Device. (5) They are mostly **patient-directed** or directed both at patients and providers, but not providers only. As an additional aspect, regulatory approval often entails that DTx can be prescribed to patients by healthcare providers.

As shown in Table 1, DTx acquire an interesting nexus position between consumer-grade mobile apps and wearables on the one hand and safety- and quality-controlled Software as a Medical Device on the other hand. This makes DTx also conceptually interesting since one needs to (a) make sure they are safe and have high efficacy while (b) make sure they appeal to consumers with increasing demands for usability, ease of use, and connectability. The table summarizes the given definitions based on relevant dimensions.

3 DTx: State-of-the-Art

DTx research is only emerging and can be approached by the definition criteria of DTx (1. purpose specific to a medical condition, 2. therapeutic intervention/mechanism of action, 3. clinically evaluated: required efficacy, safety, and quality, 4. delivered by software applications, 5. mostly patient-directed, additional aspect: reimbursable).

DTx are directed towards a ***specific medical purpose*** and thus medical diagnosis or condition. Following their

[4] According to the FDA (2019), mobile medical apps (MMAs) are medical devices that are mobile apps, meet the definition of a medical device, and are an accessory to a regulated medical device or transform a mobile platform into a regulated medical device.

[5] Different additional restrictions might apply for DTx in specific country contexts, for example, that they are a medical device of lower risk classes (I or IIa) in Germany.

Table 1 DTx and related concepts

	Software-as-a-medical device (SaMD)	Digital therapeutics (DTx)	Mobile health (mHealth)
Patient- or therapist-directed	Both	Both, but mostly patient-directed[1]	Both, consumer-grade experience
Medical purpose	Universal medical purpose	Only (diagnostic and) therapeutic purposes[2], no primary prevention	Universal health and wellness purpose
Technical aspects	Defined as software, both mobile or non-mobile	Diagnostic and therapeutic interventions by software applications, both mobile or non-mobile	Defined as practices supported by mobile devices, only mobile
Regulatory aspects	Following standards of medical device regulations, data protection regulations	Following standards of medical device and data protection regulations, further regulated regarding, e.g., efficacy and quality by regulatory frameworks of the respective region/country	For health data processing: general data protection regulation (GPDR) in Europe, HIPAA in the US
Definition frameworks by regulatory bodies	International medical device regulators forum (IMDRF), medical device regulation (MDR)	E.g., FDA medical device regulation (US); Social law; Digitale versorgungs-gesetz [Digital Healthcare Act] (DVG) (Germany)	Global observatory for eHealth (GOe) (WHO)

[1]Primary purpose, including apps that are patient-and-physician-centered

[2]For instance, FDA: prevention, management, or treatment of mental or physical conditions; Germany: detection, monitoring, treatment, abatement of diseases or disabilities or injuries

most used mode of action (behavior and lifestyle change), DTx companies currently target mostly chronic, behavior-modifiable conditions and conditions with significant unmet needs by current forms of treatment. Therefore, fields of medical indications so far are a broad spectrum of mental disorders (anxiety, depression, substance use disorders, autism spectrum disorder, chronic pain, posttraumatic stress disorder (PTSD), stress and burnout, ADHD, vaginismus, and insomnia), neurological disorders (multiple sclerosis, migraine, stroke, aphasia), endocrine and metabolic diseases (diabetes, adipositas), respiratory diseases (Asthma, COPD), cancer, tinnitus, organic impotence, birth control and orthopedics (back pain, knee conditions). The National Association of Statutory Health Insurance Funds in Germany released a report on usage of DTx two years after first approvals: Most frequently used were applications for weight reduction (28,000 users), chronic pain (27,000 users) and tinnitus (27,000 users) (GKV SV 2023). DTx to date have largely targeted psychiatric conditions or psychological strain caused by somatic diseases with significant unmet needs that are challenging to manage with existing therapeutics.[6] In the pipeline of development/market access are therefore applications addressing also severe mental disorders like bipolar disorder (e.g., Mindpax) or schizophrenia (Click Therapeutics), which can fall under higher risk classes. Regulatory barriers (e.g., limiting DTx to Medical Device Risk Class I and II a only in Germany) will eventually affect the development of apps addressing more severe or acute medical conditions. For example, Click Therapeutics is developing a DTx for Schizophrenia, but also for Acute Coronary Syndrome.

DTx are defined as ***therapeutic interventions*** and might serve as a complementary strategy, as an improvement/enhancement of an existing therapeutic strategy (e.g., in combination) or as a replacement of other therapeutics (e.g., pharmacotherapy or psychotherapy). Most DTx so far have been developed as standalone solutions, although there are also other use cases.[7] Many of the indications which are currently targeted by DTx have so far been therapeutically approached with a behavioral or psychological mode of management, for instance, Cognitive Behavioral Therapy (CBT), exercises, symptom tracking, and knowledge transfer.[8] Until now, most DTx convert these so far in-person services into a digital product. They do not only address mental disorders directly but also somatic disorder like diabetes, chronic pain or multiple sclerosis or psychological effects of somatic conditions

[6] E.g., 19 out of 42 to this date (February 2023) approved or preliminarily approved DTx in Germany address mental disorders (mainly depression and anxiety).

[7] For example, the Digital Therapeutic reSET-0 (US) provides digital Cognitive Behavioral Therapy (CBT) as an adjunct therapy to a substitution treatment with buprenorphine for patients with opioid use disorder (reSET 2020). The application Invirto (Germany) provides a CBT-based exposure treatment via Virtual Reality for phobic anxiety disorders which can only be applied while integrated in a parallel personal psychotherapy.

[8] Many DTx directed towards mental health conditions can be used without other forms of therapy as stand-alone applications but are mostly recommended in case of unavailability of psychotherapy.

(e.g., after stroke, cancer) mainly through behavioral change by means of CBT-based mechanisms. Only few so far use additional mechanisms of action like sensor-based monitoring (e.g., connection to blood glucose meter via diabetes pump (BlueStar App)), biofeedback (e.g., via carbon dioxide gas analyzer in panic disorder (Freespira)), Artificial Intelligence (AI) (broca-software by GAIA used in several apps), gaming (video game for pediatric ADHD, EndeavorRx) or virtual reality (VR) (e.g., Invirto).

Clinically evaluated. Regulatory bodies have held that DTx need to be *clinically evaluated* regarding efficacy, safety, and quality. The first aspect of clinical evaluation describes the conscientious, explicit and judicious use of currently accepted best practices to show evidence of the efficacy of a DTx (cf. Sackett 1996; Huh et al. 2022). DTx companies, together with research institutes, have started research studies to evaluate outcome improvements via DTx. This research has produced evidence of varying levels, ranging from single descriptive studies, pre-/post observational studies, to randomized controlled trials (RCTs) and meta-analyses (see e.g., Lantzsch et al. 2022 for Germany). While such research has mostly focused on medical benefits (morbidity, mortality, or quality of life), some studies by DTx companies have also aimed at demonstrating patient-relevant structural and procedural benefits, which were introduced and defined as a new concept of positive healthcare effects under the social law framework with the Digital Healthcare Act in Germany. These include benefits to health literacy, therapy adherence, or facilitated access to care.[9] Required evidence will be presented to the respective regulatory bodies during the approval process by DTx companies. In Germany, for example, a register of DTx for patients and providers is provided online by the regulatory body (BfArM) summarizing the presented evidence using the PICO-reporting standard. However, only a part of the presented evidence can be accessed in form of scientific publications which make the evidence broadly available to the research community (see inaccurate characterization of antidepressant efficacy by publication bias (FDA registration vs. published studies; Turner et al. 2008)). So far, mainly evidence in form of controlled trials has been published coming with the limitations of controlled study settings and selected patient samples.[10] Also, studies on economic outcomes like cost-effectiveness are scarce,[11] although pricing is an ongoing debate regarding DTx.

In addition, DTx need to be *safe*. By that, we refer to aspects of patient safety. The WHO (2019) defines patient safety as a health care discipline which "aims to prevent and reduce risks, errors and harm that occur to patients during provision of health care". Adverse event monitoring is part of Good Clinical Practice and is ethically required also for non-invasive interventions such as psychological interventions and, more specifically, DTx. In addition to basic technical safety, this includes measures to recognize and prevent risky health situations caused by DTx.

Required *quality* refers to the required adherence to standards defined by regulatory bodies. These standards encompass a broad range of issues, such as data protection, information security, interoperability, and further quality requirements such as robustness, consumer protection, ease of use, support of healthcare providers, and quality of medical content (BfArM 2022). To specifically pick two areas, data protection and information security, regulatory bodies in Germany require that DTx users must be able to rely on the fact that the manufacturer complies with legal requirements for data protection, handles their data carefully and implements measures to protect confidentiality, availability and integrity. Risks to data protection and information security must be analyzed and evaluated and, if necessary, appropriate measures must be taken to protect the data. Informed consent and transport layer security will probably be unavoidable here. In the case of a high protection requirement, measures of end-to-end encryption will certainly also have to be provided. As another area, standards also concerns interoperability requirements such as mandatory interfaces to the national electronic health record and adherence to standards for device connectivity.

DTx are delivered through ***software applications*** and therefore several technological aspects should be considered. To date, DTx are as a majority delivered through native mobile apps; other forms of delivery used so far are web apps, a combination of native apps and web apps or computer software. Additionally, certain DTx only or possibly are used in combination with some form of hardware device (or medical device). For example, applying forms of sensor-based-monitoring through connection to a blood glucose meter via diabetes pump (MySugar App), biofeedback via a Carbon dioxide gas analyzer in panic disorder (Freespira) or a digital inhaler with built-in sensors for COPD/Asthma (ProAir Digihaler), generally falling under regulations of medical devices. Some DTx are connected with consumer devices like wearables (e.g., the

[9] For instance, vorvida, a Digital Therapeutic for alcohol use disorder, not only demonstrated a reduction in alcohol consumption but also patient autonomy.

[10] Only the application deprexis (depression treatment) provided a real-world-evidence study so far, showing similar positive pre-post-effects compared to RCT findings among 104 patients. It has submitted two RCTs and a meta-analysis to demonstrate a reduction in depressive symptoms (see e.g., Meyer et al. 2015).

[11] Only deprexis showed a reduction of health insurance costs in the intervention group vs. a control group (32% vs.13%) (Gräfe et al. 2020).

insomnia app Somnio can be used in combination with a fitness tracker; the actigraphy sensor for activity tracking in bipolar disorder applied by Mindpax) or VR-devices (Invirto app for phobic anxiety disorders using VR-glasses). This means it is necessary to develop interfaces to add-on-consumer devices as well as medical devices, but also other interface sections (e.g., telehealth software; or legally required interfaces to electronic health records). Another technical component only singularly used so far is gaming: EVO by Akili Interactive is an example of a serious game, which is FDA cleared for prescription to treat pediatric ADHD (FDA 2020). A part of DTx uses advanced Artificial Intelligence (AI) technologies (i.e., AI, machine learning, deep learning) to provide customized and adaptive algorithms and interventions. In most cases, this is applied as some form of automated process, for instance, a virtual dialogue. For example, the company GAIA uses its AI-system broca in several DTx (deprexis for treatment of depression, vorvida for the treatment of alcohol use disorder and others) and its further broadening its application (e.g., multiple sclerosis). This software employs a rule-based artificial intelligence (AI) approach in order to custom-tailor information to match individual needs and preferences that users indicate by selecting specific responses during a virtual dialogue. Kaia Health developed an artificial intelligence-based computer vision technology, which enables smartphone and tablet to record and analyze the user's movement patterns during exercises for real-time analysis and provides live, corrective feedback (e.g., for back pain, Digital Therapeutic for approval in pipeline). More advanced methods using AI-prediction and modeling have so far not been applied in forms of DTx. However, promising studies do show, for instance, possibilities of AI-based symptom prediction although applied models are heterogenous and based on small study samples (Ortiz et al. 2021). DTx potentially generate large amounts of useful data. Currently, use of this data is highly entangled in debates about security and privacy regulations as well as standardized data formats, and therefore not used so far.

DTx are defined as ***patient-directed*** or both patient-and-physician-directed, defining the patient as the main user of the application. Although combined patient-and-physician-directed applications are possible, only a minority use this possibility like the VR app Invirto, which is integrated in a psychotherapeutical process. Although not obligatory, a major part of applications offer some form of symptom or progress report which can be shared with the physician. So far DTx are mainly used by women (70% of users of DTx for neurological conditions were female in Germany) and used in urban centers (e.g., Berlin, Hamburg) (Dtsch Arztebl 2022). In a poll among 2.200 US adults in June 2021, 73% described digital health tools as convenient, while 60% said they were safe and 56% said they were accurate (Galvin 2021). Also, existing solutions mainly address an outpatient setting and stand-alone use. Applications addressing hospital settings or management at intersections are missing. Although the patient is defined as the main user, regulatory approval often entails that DTx can be prescribed to patients by healthcare providers or in case of direct-to-consumer application a medical diagnosis is needed to achieve reimbursement by health insurance. Still, in Scotland people are able to self-refer or visit their GP to receive Big Health's DTx for anxiety and insomnia for free via the NHS as self-prescription (Lovell 2021). Other reimbursement strategies like out-of-pocket-pay highly depends on the respective region and often not common in insurance-based countries. Thus, physicians play a major role in recommending, explaining, monitoring, motivating and prescribing DTx to their patients, integrating them into a holistic therapeutic concept and weighting them against different treatment options. Hence, the diffusion of DTx is highly related to the acceptance and knowledge of health professionals. Studies among German physicians reveal that 24–62% would potentially prescribe a digital therapeutic (Haserück 2021; Dahlhausen et al. 2021), but in a different study 56% reported to feel poorly prepared for prescription (Barmer 2020).

As described by Brinkmann-Sass et al. (2020), the reimbursement pathway in countries differs, is generally complex, and involves considerable upfront costs and investments. This means that a predefined pathway to prescription opens up a new market. For example, starting with first approvals in October 2019, so far 47 DTx have been (preliminary) approved in Germany,[12] and around 35–40 in the US starting in 2017. Companies have partnered with large pharmaceutical companies or attracted significant venture financing: Pear Therapeutics, a company developing a Digital Therapeutic for substance and opioid use disorder, has raised $139 million and Akili Interactive, a company developing a Digital Therapeutic for Attention Deficit Hyperactivity Disorder and Autism Spectrum Disorder, has raised $119 million (Patel and Butte 2020). Current pricing in Germany ranges between 119 € and 952 € for 90 days application use, with first

[12] While DTx in Germany may be preliminary approved for a trial period if they can show their fulfillment of the defined safety criteria and standards, they will only receive permanent approval if they can demonstrate their adherence to safety criteria and standards and sufficient evidence for positive effects on care. Up to March 2022, 124 applications for approval have been submitted to the regulatory body in Germany with an approval rate of 25% so far mainly due to high evidence and quality standards (20% still under assessment, 6% rejected, 50% retrieved) (BfArM 2022). As of February 2023, 7 DTx have been removed since the trial period ended, leaving currently 42 approved DTx (preliminary or permanent) at the time of this writing (February 2023).

forced price reduction for the insomnia app Somnio (Hoffmann 2022). Value-based reimbursement arrangements would be a manageable strategy considering the possibilities of adherence monitoring in DTx compared to other forms of therapy (e.g., pharmacotherapy) (see Gensorowsky et al. 2022 for a specific proposal). But only one application offers an innovative usage-based pricing model so far (if a patient uses less than two modules, 0 € will be charged for the three different apps by Selfapy addressing anxiety and depression, Pay-for-Performance).

4 Future Research

In the following, we outline promising areas of research for BISE/IS scholars regarding DTx. For this, we introduce the **DTxSV** (DTx data, technology, social process integration, value) **framework** shown below and locate areas of research across different problem dimensions (see Fig. 2a). We also locate research areas across levels–from more micro (individual) to more macro (societal) topics (see Fig. 2b). We will discuss these research areas in the following.

While DTx have been conceptualized as specific (digital) interventions targeted towards specific diseases, disease patterns are often complex and multi-faceted. With aging societies, lifestyle factors, and an increase in chronic conditions, we see a need for customized digital interventions based on a comprehensive picture of the patient (e.g., Bardhan et al. 2020). The DTx concept and a related research agenda could advance work on ① **self-management of health** (e.g., Dadgar and Joshi 2018) in several ways. First, DTx are patient-directed and designing such specific interventions for specific patient pathways can improve our knowledge in how to create better and better evaluated interventions. Going even beyond recent work by Ghose et al. (2022), through DTx we can extend our knowledge of how to better manage health via mobile technology. Second, DTx provide new sources of real-world data and interactions with DTx manufactures may yield interesting new strategies for behavioral interventions and digital nudges (Lehrer et al. 2021). DTx are often combined with wearables and other devices so that studying them can improve our knowledge about individual patterns of technology use, reflection, and action (Constantinou et al. 2022).

Similarly, the DTx concept may help to advance our understanding of ② **patient-/user centricity**. Patient centricity firstly means that patients are actively and continuously involved in developing and improving a digital solution. Against the background of a challenging implementation context with often oppositional views towards new technology (e.g., Oborn et al. 2011), *patient advocacy* in which solutions are not developed for but with users, could potentially help to mitigate or avoid common pitfalls in prior healthcare IT implementations, such as strong resistance (Lapointe and Rivard 2005). Such patient advocacy can trickle into regulatory guidelines and standards due to the DTx being (at least partly) state-paid, as ill-designed DTx may be a burden for patients who may not

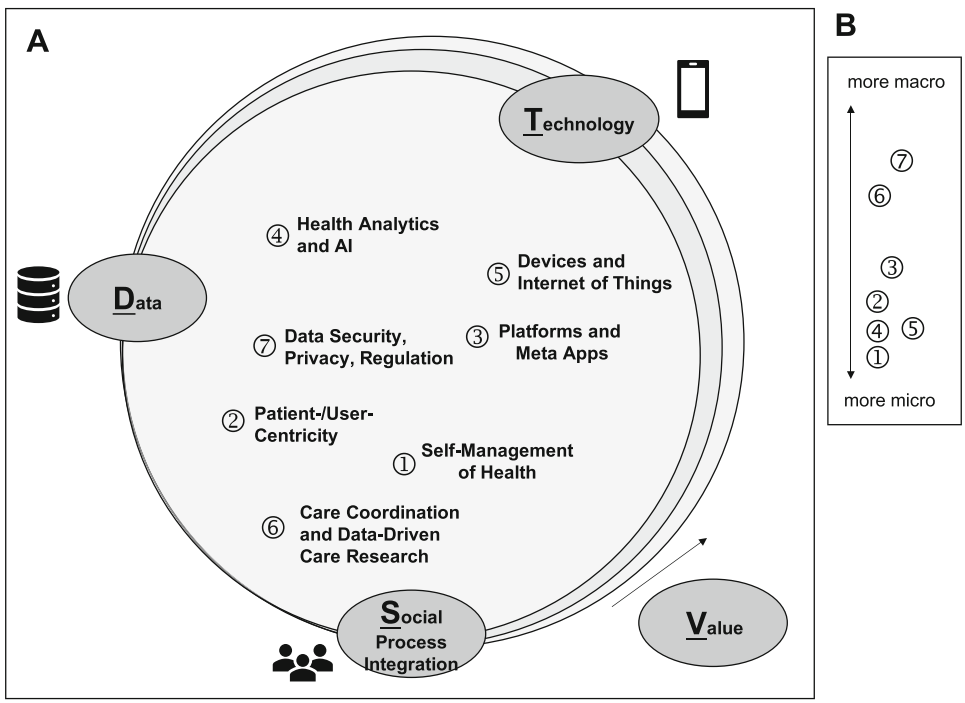

Fig. 2 DTx future research areas

want to use them but need to (as DTx target sick and are prescribed). Consequently, the DTx concept may spur research into new forms of user participation and mandatory use (Bhattacherjee et al. 2018), while paternalistic decision-making could force users to adopt an innovation they may later abandon.

Patient-centricity further means that DTx are continuously evaluated for improvement of relevant dimensions of patient-centric *outcomes*. This area of research is strongly connected to the value dimension of the DTxSV framework. DTx enable the continuous tracking of important indicators of patients' quality of life, pain levels, disease burden, etc. Such patient-reported outcomes (PROMs) have long been considered an important dimension of the value created for patients in medical encounters. DTx are PROM tools. While some BISE/IS researchers have investigated the patient value of mHealth apps, for instance, regarding therapy adherence (Ghose et al. 2022) or broader value dimensions (including ethical, social, and epistemic) (Barrett et al. 2016), DTx require further evidence to establish their efficacy. This can conceptually help to develop our understanding of value and outcomes, especially since DTx also bring the opportunity to be highly adaptive after implementation.

While positive care effects from DTx are being considered, the workload of medical staff or economic indicators of healthcare as well as unwanted events and outcomes are not yet investigated as relevant endpoints. While the reporting of adverse effects in biomedical research (e.g. pharmacotherapy) is usually based on a straightforward definition of harmful events, defining and measuring unwanted events related to DTx use such as adverse treatment reactions, side effects, malpractice reactions, treatment non-response, or deterioration of illness is a field that deserves attention. This refined attention to unintended consequences of "techno-centric designs" (Dadgar and Joshi 2018) could include technostress of using apps as medical tools, unfavorable algorithmic control, being nudged into safety–critical situations, or unwilling addiction to the therapeutic. Research on suitable outcomes and methodologies is scarce, presenting considerable possibilities for research.

Furthermore, a patient may already today use a plethora of DTx in combination (e.g., for diabetes management, obesity, and depressive symptoms). In the future, the concept of DTx can expand our understanding of ③ **platforms/meta apps** providing an integrated and tailored user experience to patients/users. Building on a tradition of research on electronic health records (e.g., Oborn et al. 2011; Hansen and Baroody 2020), this touches new ground in the technology and data dimension, since we need more understanding of platform concepts and data exchange standards in contexts where consumer-grade devices interact with large-scale infrastructural technologies. This includes the transfer of data among multiple DTx combined under one umbrella plus standardized interfaces with electronic health records, prevention apps, and wearables. DTx research can thereby shine a new light on interoperability in "hyper-connected ecosystems" (Hodapp and Hanelt 2022). Platform research in the context of DTx also concerns the social process dimension. Through DTx, we can understand how integrated user journeys can be designed so that DTx in combination with other apps and platforms can benefit patients/users in everyday practice (including potentials, limits or unwanted effects of behavioral strategies such as nudging, compliance). Building also on the intense study of on multi-sided platforms in healthcare IT (e.g., Yaraghi et al. 2015; Fürstenau et al. 2019), research can show whether conflicting interests and tensions will further amplify or whether new digital coordination mechanisms and transparencies can be used for a better alignment of interests. The concept of DTx also spurs research to looking into the social processes regarding governance and responsibilities, especially the question who should run and appropriate value from such DTx-infused platforms, which are at least partly paid by the public system.

We also suggest research into ④ **health analytics and artificial intelligence (AI),** their implications, and risks in the context of DTx. For example, motion capturing via smartphone cameras, as with Kaia Health, produces large data amounts for designing personalized training programs, and validates and optimizes these programs over time via real-world evidence. As another example, virtual bots have been introduced to mimic/emulate human/therapists' behaviors (Makin 2019; Weimann et al. 2022). Beyond research into the potentials of AI, we also need a careful evaluation of when to use AI at all, for what purpose,[13] how decisions supported by AI are reached, how accurate such conclusions are, and whether there is a demonstrable clinical benefit from AI applications with DTx (Liu et al. 2020). Research in this area also concerns pressing ethical and legal questions, such as whether responsibility can be delegated to an algorithm or how to deal with missing or misrepresented training data which lead to biased decisions.

The DTx concept can also provide new avenues for research into ⑤ **devices and Internet of Things (IoT)-based monitoring**. With new and exciting wearables under way, such as consumer-grade watches, rings, and smart

[13] Research by Google and other firms has provided some guidance on when to automate and when to augment tasks performed by humans via AI, showing that especially unpleasant, difficult tasks that can be scaled may be automated via AI, while more enjoyable, social tasks, that do not have one correct way, may hold promise for augmentation (Google Research 2022).

textiles with medical functions such as the ability to track sleep, activity, glucose levels, heart rate, ECGs, and others, we see increasing potentials to integrate DTx with the constant monitoring of vital parameters. This extends–and partly replaces–failure-prone manual diary inputs and enables the pooling of large-scale longitudinal continuous data, which can be used for AI-based predictions. For instance, device data from Apple watches has shown promising results in many fields of medicine, including cardiology, where ECG data has been used to detect Atrial Fibrillation (Perez et al. 2019). Beyond monitoring and an embodiment perspective of changes in work practices (e.g., via robotic surgery; e.g., Sergeeva et al. 2020), the potentials of implants such as neuro implants promise that DTx actively intervene into patient physiology, calling for research into risk assessments of hybrid physical-digital (phygital) artefacts. Building on prior research that has noted that often a digital artefact (e.g., an app) supplements hardware components to assess data and provide user feedback (Abouzahra and Ghasemaghaei 2022; Benbunan-Fich 2019), this adds important research questions of interoperability, changes in life and work practices, and process integration for individuals and medical professionals.

Building thereupon, we call for research into ⑥ **care coordination and data-driven care research** enabled via DTx as building blocks of digital care journeys. Here, research is needed to understand the extent to which data may be used for active management of care pathways and related questions on roles and responsibilities. This can present an interesting field of application for research into reputation systems, ratings, and other economic coordination mechanisms. It also advances social process integration-driven research into cross-sectoral, cross-professional managed care innovations, including aspects of architecture and governance. These have been important topics of research for digital platforms, which can now be investigated for DTx-enabled care pathways. Essentially, the goal is stronger patient involvement and the sharing of decisions between healthcare professionals and patients, which opens questions regarding societal and individual patterns shaping decision making in DTx contexts. Also, potentially unwanted effects make up an important field of research, e.g. methods of understanding these effects in complex systems. BISE/IS researchers have long established the importance of platforms for coordinating market participants. Regarding DTx, we need to understand the complex sets of stakeholders involved within the value creation via DTx, their economic and other interests, and the business models by which they appropriate the value created.

The trends outlined including DTx apps, devices, and wearables enable the creation of increasingly large pools of data. These can be processed and analysed not only to improve individual patient outcomes, but increasingly motivate *data-driven care research* (Fürstenau et al. 2021). With digital support for patient-centered therapy, there is a growing need for trustworthy integration of both a patient's previously distributed data over the course of therapy with all the health data of his or her life to date, and the opportunity for new insights through the structured analysis of aggregations of as many digital patient histories as possible. This calls for research into federated data spaces and newly invented value chain activities, like data aggregator or data trustee, as parts of emerging **data ecosystems,** and needed solutions for data governance, metadata management, and data lifecycle management (e.g., Otto and Jarke 2019). Various legal, technical, but also economic and communicative measures can be suitable for facilitating the consents to data use despite existing uncertainties. These range from "trustworthiness by design", for instance, the use of standards and technologies like blockchain or cryptography, diverse certifications and insurances to pledging by brands, and a more emotional signalling of trustworthiness. Data aggregators realize the integration of data according to defined medical, ethical, organizational and technical quality standards, including the maintenance of metadata, and the curation of data during its life. There is a great need for research into different also separated design options for these increasingly relevant tasks.

Finally, we see the need for research into ⑦ **data security, privacy, and regulation**. Building upon the plethora of research into these aspects with mHealth apps (e.g., Dehling et al. 2015; Sunyaev et al. 2015; Hussain et al. 2019; Zhou et al. 2019; Aljedaani and Babar 2021), the specific requirements of DTx as Software as a Medical Device make it important to pay particular attention to their security and privacy. For instance, German DiGA regulation prohibits the use of advertising to restrict inappropriate data flows, which may harm privacy. Recent cases of sensitive medical data from a DTx app accessible on the internet posed an unacceptable threat to patients, and also created a lively public debate about the actual procedure through which DTx in Germany are tested for their security (Heise 2020). Regarding privacy, dozens of depression and smoking cessation apps share data with third parties for advertising and other purposes, often without any disclosure to, or consent from, the individuals using the applications (Huckvale et al. 2019). This can be considered relevant in the case of DTx since they are directed towards a medical diagnosis which includes highly sensitive health data. Even when health information is stripped of personal identifiers, it can often be re-identified with little effort. For instance, researchers were able to re-identify up to 95 percent of individual adults from the National Health and Nutrition Examination Survey using machine learning

techniques (Na et al. 2018). Especially for DTx that are prescribed to large populations with potentially severe conditions, this illustrates the importance of research into security and privacy, as well as highlights that contextual privacy norms will not only be based on technical but also broad ethical considerations that evolve over time (Nissenbaum 2010).

5 Conclusion

With exciting developments ahead, we call the BISE/IS community to advance our field via research on DTx. There is a long-standing tradition of research into healthcare IT: Beyond research into large-infrastructural technologies such as EHRs and health information exchanges, it has also increasingly attended to consumers playing a major role in healthcare journeys (Baird et al. 2020). DTx are continuing this trend and are positioned in a conceptually interesting position between consumer-grade mobile apps and wearables on the one hand and safety- and quality-controlled Software as a Medical Device on the other hand. While prior findings about healthcare IT will act as an excellent vantage point, their nature on the nexus between two spheres makes it worth investigating DTx and to call for studies to understand their characteristics and intended and unintended consequences.

We see the BISE/IS community adding to all dimensions of our framework: technology, data, social process integration, and value. Regarding the *technology* dimension, there is a strong design science research community: Unique for BISE/IS researchers are broad capabilities in conceptual modeling (Recker et al. 2021), system analysis (Truex et al. 2010), and design theorizing (Gregor 2006; Baskerville et al. 2018)–more than what is usual in neighboring disciplines such as medical informatics. This can help to describe practical problems in a comprehensive and contextualized way, supporting the creation of useful DTx. BISE/IS researchers are also in a privileged position to use their proficiency in data analytics and artificial intelligence. In doing so, BISE/IS researchers can foster innovative uses which the *data* generated through DTx. They can not only help in creating powerful algorithms to support clinical and patient decision making (and thus improve service quality), but they can also use this knowledge to track important outcomes and foster outcome and public health research necessary to tackle the grand challenges of our time such as epidemiological crises or an aging society. BISE/IS researchers from various traditions can also contribute to the *social process* integration of DTx to foster their broader adoption and diffusion. The increasing number of DTx will make it hard for the consumer/patient and for medical professionals to select among them in the future. BISE/IS researchers are in a unique position to understand the socio-technical challenges in healthcare platform design and management (Fürstenau et al. 2019). Therefore, they can offer support in creating viable platform ecosystems, which use the principles of the platform economy to support patient care. Finally, BISE/IS researchers can also aid the analysis of the *value* created via DTx. While other disciplines such as implementation science (Damschroder et al. 2009) and health economics (Garrido et al. 2010) have made important contributions regarding respective methodologies, BISE/IS researchers bring unique capabilities in management science and mechanism-design to the table that support a more in-depth evaluation of the economic implications and increase the patient-centeredness of DTx.

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References

Abouzahra M, Ghasemaghaei M (2022) Effective use of information technologies by seniors: the case of wearable device use. Eur J Inf Syst 31:241–255. https://doi.org/10.1080/0960085X.2021.1876534

Aljedaani B, Babar MA (2021) Challenges with developing secure mobile health applications: systematic review. JMIR mHealth uHealth 9(6):e15654. https://doi.org/10.2196/15654

BMG (2020) Digital healthcare act (DVG): driving the digital transformation of Germany's healthcare system for the good of patients. https://www.bundesgesundheitsministerium.de /digital-healthcare-act.html

Baird A, Angst C, Oborn E (2020) Health information technology. In: Bush A, Rai A (eds.), MIS quarterly research curations. http://misq.org/research-curations

Baltic Times (2021) The digital therapeutics Vigo, created by a Latvian start-up, becomes the first in the Baltics that the state will be able to reimburse. https://www.baltictimes.com/the_digital_therapeutics_vigo__created_by_a_latvian_start-up__becomes_the_first_in_the_baltics_that_the_state_will_be_able_to_reimburse/

Bardhan I, Chen H, Karahanna E (2020) Connecting systems, data, and people: a multidisciplinary research roadmap for chronic disease management. MIS Q 44:185–200

Barmer (2020) Barmer-Umfrage zu Gesundheits-Apps–Ärzte stehen digitalen Helfern offen gegenüber. https://www.barmer.de/presse/bundeslaender-aktuell/schleswig-holstein/archiv-presse mitteilungen/umfrage-app-diga-247896

Barrett M, Oborn E, Orlikowski W (2016) Creating value in online communities: the sociomaterial configuring of strategy, platform, and stakeholder engagement. Inf Syst Res 27:704–723. https://doi.org/10.1287/isre.2016.0648

Baskerville R, Baiyere A, Gregor S et al (2018) Design science research contributions: finding a balance between artifact and theory. J Assoc Inf Syst 19:358–376. https://doi.org/10.17705/1JAIS.00495

Benbunan-Fich R (2019) An affordance lens for wearable information systems. Eur J Inf Syst 28:256–271. https://doi.org/10.1080/0960085X.2018.1512945

BfArM (2022) The fast-track process for digital health applications (DiGA) according to Section 139e SGB V: a guide for manufacturers, service providers and users. https://www.bfarm.de/SharedDocs/Downloads/EN/MedicalDevices/DiGA_Guide.pdf

Bhattacherjee A, Davis CJ, Connolly AJ, Hikmet N (2018) User response to mandatory IT use: a coping theory perspective. Eur J Inf Syst 27:395–414

Brinkmann-Sass C, Richter L, Silberzahn T, Somauroo A (2020) The European path to reimbursement for digital health solutions. McKinsey Q 3:1–8

Brown D (2021) Digital therapeutics regulation: 3 leading countries (inc. FDA, MDR, & DiGA). https://www.smartpatient.eu/blog/fda-mdr-digital-therapeutics-regulation-leading-countries

Constantiou I, Mukkamala A, Sjöklint M, Trier M (2022) Engaging with self-tracking applications: how do users respond to their performance data? Eur J Inf Syst. https://doi.org/10.1080/0960085X.2022.2081096

DTA (2022) Digital therapeutics alliance–DTx by country. https://dtxalliance.org/understanding-dtx/dtx-by-country/

Dadgar M, Joshi KD (2018) The role of information and communication technology in self-management of chronic diseases: an empirical investigation through value sensitive design. J Assoc Inf Syst 19:86–112. https://doi.org/10.17705/1jais.00485

Dahlhausen F, Linn Bieske M, Ehlers JP et al (2021) Physicians' attitudes toward prescribable mHealth apps and implications for adoption in Germany: mixed methods study. JMIR mHealth uHealth 9:e33012. https://doi.org/10.2196/33012

Damschroder LJ, Aron DC, Keith RE et al (2009) Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implement Sci 4:1–15. https://doi.org/10.1186/1748-5908-4-50

Dehling T, Gao F, Schneider S, Sunyaev A (2015) Exploring the far side of mobile health: information security and privacy of mobile health applications on IOS and Android. JMIR Mhealth Uhealth 3:e8. https://doi.org/10.2196/mhealth.3672

FDA (2019) Proposed regulatory framework for modifications to artificial intelligence/machine learning (AI/ML)-based software as a medical device (SaMD)–discussion paper and request for feedback. Food and Drug Administration, Silver Spring, pp 1–20

FDA (2020) FDA permits marketing of first game-based digital therapeutic to improve attention function in children with ADHD. https://www.fda.gov/news-events/press-announcements/fda-permits-marketing-first-game-based-digital-therapeutic-improve-attention-function-children-adhd

Fürstenau D, Auschra C, Klein S, Gersch M (2019) A process perspective on platform design and management: evidence from a digital platform in health care. Electron Mark 29:581–596

Fürstenau D, Klein S, Vogel A, Auschra C (2021) Multi-sided platform and data-driven care research: a longitudinal study on business model innovation for improving care in complex neurological diseases. Electron Mark 31:811–828

GKV SV (2023) Bericht des GKV-Spitzenverbandes über die Inanspruchnahme und Entwicklung der Versorgung mit Digitalen Gesundheitsanwendungen (DiGA-Bericht). https://www.gkv-spitzenverband.de/media/dokumente/krankenversicherung_1/telematik/digitales /2022_DiGA_Bericht_BMG

Galvin G (2021) COVID-19 Accelerated use of digital therapeutics, but coverage issues and regulatory questions could slow their momentum. https://morningconsult.com/2021/06/15/digital-therapeutics-use-coverage-polling/

Garrido MV, Gerhardus A, Røttingen JA, Busse R (2010) Developing health technology assessment to address health care system needs. Health Policy 94:196–202. https://doi.org/10.1016/j.healthpol.2009.10.002

Gerke S, Stern AD, Minssen T (2020) Germany's digital health reforms in the COVID-19 era: lessons and opportunities for other countries. NPJ Digit Med 3:1–6. https://doi.org/10.1038/s41746-020-0306-7

Ghose A, Guo X, Li B, Dang Y (2022) Empowering patients using smart mobile health platforms: evidence of a randomized field experiment. MIS Q 46:151–191

Google Research (2022) The people+AI guidebook. https://pair.withgoogle.com/guidebook/

Gregor S (2006) The nature of theory in information systems. MIS Q 30:611–642

Gräfe V, Moritz S, Greiner W (2020) Health economic evaluation of an internet intervention for depression (deprexis), a randomized controlled trial. Health Econ Rev 10(1):19. https://doi.org/10.1186/s13561-020-00273-0

Hansen S, James Baroody A (2020) Electronic health records and the logics of care: complementarity and conflict in the U.S. healthcare system. Inf Syst Res 31:57–75

Haserück A (2021) Digitalisierungsaffinität: ausgangslage unterschiedlich. Dtsch Arztebl 118:A-285-B−249

Heise (2020) Sicherheitslücken in "App auf Rezept" gegen Angsterkrankungen entdeckt. https://www.heise.de/news/Sicherheitsluecken-in-App-auf-Rezept-gegen-Angsterkrankungen-entdeckt-4927160.html

Hodapp D, Hanelt A (2022) Interoperability in the era of digital innovation: an information systems research agenda. J Inf Technol. https://doi.org/10.1177/02683962211064304

Hoffmann L (2022) App auf Rezept gegen Schlafstörung kostet nur noch die Hälfte. https://www.handelsblatt.com/inside/digital_health/schiedsgerichturteil-app-auf-rezept-gegen-schlafstoerung-kostet-nur-noch-die-haelfte-/27998110.html

Hong JS, Wasden C, Han DH (2021) Introduction of digital therapeutics. Comput Methods Programs Biomed 209:106319. https://doi.org/10.1016/j.cmpb.2021.106319

Hoyt RE, Hersh WR (2018) Health informatics: practical guide. Informatics Education, Singapore

Huckvale K, Torous J, Larsen ME (2019) Assessment of the data sharing and privacy practices of smartphone apps for depression and smoking cessation. JAMA Netw Open 2:e192542. https://doi.org/10.1001/jamanetworkopen.2019.2542

Huh KY, Oh J, Lee S, Yu KS (2022) Clinical evaluation of digital therapeutics: present and future. Healthc Inform Res 28:188–197. https://doi.org/10.4258/hir.2022.28.3.188

Hussain M, Ahmed Al-Haiqi A, Zaidan AA et al (2019) A security framework for mHealth apps on android platform. Comput Secur 75:191–217

IMDRF (2013) International medical device regulation forum – software as a medical device (SaMD): key definitions. http://www.imdrf.org/docs/imdrf/final/technical/imdrf-tech-131209-samd-key-definitions-140901

Lapointe L, Rivard S (2005) A multilevel model of resistance to information technology implementation. MIS Q 29:461–491. https://doi.org/10.2307/25148692

Lehrer C, Eseryel UY, Rieder A, Jung R (2021) Behavior change through wearables: the interplay between self-leadership and IT-based leadership. Electron Mark 31:747–764

Liu X, Cruz Rivera S, Moher D, Calvert MJ, Denniston AK, Ashrafian H et al (2020) Reporting guidelines for clinical trial reports for interventions involving artificial intelligence: the CONSORT-AI extension. Lancet Digit Health 2:e537–e548. https://doi.org/10.1016/S2589-7500(20)30218-1

Lovell (2021) NHS Scotland provides access to digital therapeutics for anxiety and insomnia. https://www.mobihealthnews.com/news/emea/nhs-scotland-provides-access-digital-therapeutics-anxiety-and-insomnia

Makin S (2019) The emerging world of digital therapeutics. Nature 573:S106. https://doi.org/10.1038/d41586-019-02873-1

Meyer B, Bierbrodt J, Schröder J, Berger T et al (2015) Effects of an internet intervention (Deprexis) on severe depression symptoms: randomized controlled trial. Internet Interv 2:48–59. https://doi.org/10.1016/j.invent.2014.12.003

Myler P (2020) Digital therapeutics in the UK. https://www.s3connectedhealth.com/blog/nhs-bodies-and-organizations-relevant-to-the-approval-of-digital-therapeutics-in-the-uk

Na L, Yang C, Lo CC, Zhao F, Fukuoka Y, Aswani A (2018) Feasibility of reidentifying individuals in large national physical activity data sets from which protected health information has been removed with use of machine learning. JAMA Netw Open 7:e186040. https://doi.org/10.1001/jamanetworkopen.2018.6040

Nissenbaum H (2010) Privacy in context: technology, policy, and the integrity of social life. Stanford University, Press Redwood City

Nittas V, Lun P, Ehrler F et al (2019) Electronic patient-generated health data to facilitate disease prevention and health promotion: scoping review. J Med Internet Res 21:1–19. https://doi.org/10.2196/13320

Nordic Innovation (2018) A Nordic story about smart digital health. http://norden.diva-portal.org/smash/get/diva2:1297054/FULLTEXT01

Oborn E, Barrett M, Davidson E (2011) Unity in diversity: electronic patient record use in multidisciplinary practice. Inf Syst Res 22:547–564

Ortiz A, Maslej MM, Husain MI, Daskalakis ZJ, Mulsant BH (2021) Apps and gaps in bipolar disorder: a systematic review on electronic monitoring for episode prediction. J Affect Disord 295:1190–1200

Otto B, Jarke M (2019) Designing a multi-sided data platform: findings from the international data spaces case. Electron Mark 29(4):561–580

Patel NA, Butte AJ (2020) Characteristics and challenges of the clinical pipeline of digital therapeutics. NPJ Digit Med 3:159. https://doi.org/10.1038/s41746-020-00370-8

Perez MV, Mahaffey KW, Hedlin H, Rumsfeld JS, Garcia A, Ferris T et al (2019) Large-scale assessment of a smartwatch to identify atrial fibrillation. N Engl J Med 381:1909–1917. https://doi.org/10.1056/NEJMoa1901183

Recker J, Lukyanenko R, Jabbari M et al (2021) From representation to mediation: a new agenda for conceptual modeling research in a digital world. MIS Q 45:269–300. https://doi.org/10.25300/MISQ/2021/16027

resSET (2020) reSET for recovery. https://www.resetforrecovery.com/how-it-works

Ruckel L (2020) Boehringer ingelheim and click therapeutics enter into collaboration to develop and commercialize CT-155, a novel prescription digital therapeutic to aid in the treatment of schizophrenia. https://www.boehringer-ingelheim.us/press-release/boehringer-ingelheim-and-click-therapeutics-enter-collaboration-develop

Sackett DL, Rosenberg WM, Gray JA, Haynes RB, Richardson WS (1996) Evidence based medicine: what it is and what it isn't. BMJ 13:71–72

Sergeeva AV, Faraj S, Huysman M (2020) Losing touch: an embodiment perspective on coordination in robotic surgery. Organ Sci. https://doi.org/10.1287/orsc.2019.1343

Statista (2022) Number of mHealth apps available in the apple app store from 1st quarter 2015 to 3rd quarter 2022. https://www.statista.com/statistics/779910/health-apps-available-ios-worldwide/

Steinhubl SR, Muse ED, Topol EJ (2013) Can mobile health technologies transform health care? JAMA 310:2395–2396. https://doi.org/10.1001/jama.2013.281078

Sunyaev A, Dehling T, Taylor PL, Mandl KD (2015) Availability and quality of mobile health app privacy policies. J Am Med Inform Assoc 22:28–33. https://doi.org/10.1136/amiajnl-2013-002605

Truex D, Alter S, Long C (2010) Systems analysis for everyone else: empowering business professionals through a systems analysis method that fits their needs. In: Proceeding 2010 European conference on information systems. https://aisel.aisnet.org/ecis2010/4

Turner EH, Matthews AM, Linardatos E, Tell RA, Rosenthal R (2008) Selective publication of antidepressant trials and its influence on apparent efficacy. N Engl J Med 358(3):252–260. https://doi.org/10.1056/NEJMsa065779

WHO (2011) mHealth: new horizons for health through mobile technologies: second global survey on eHealth. WHO Library Cataloguing-in-Publication Data, Geneva

WHO (2019) Patient safety. https://www.who.int/news-room/fact-sheets/detail/patient-safety

Weimann TG, Schlieter H, Brendel AB (2022) Virtual coaches. Bus Inf Syst Eng 64:515–528. https://doi.org/10.1007/s12599-022-00757-9

Yaraghi N, Du AY, Sharman R et al (2015) Health information exchange as a multisided platform: adoption, usage, and practice involvement in service co-production. Inf Syst Res 26:1–18. https://doi.org/10.1287/isre.2014.0547

Zhou L, Bao J, Watzlaf V, Parmanto B (2019) Barriers to and facilitators of the use of mobile health apps from a security perspective: mixed-methods study. JMIR mHealth uHealth 7(4):e11223. https://doi.org/10.2196/11223

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