

# Towards adaptive technology in routine mental health care

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## Abstract

This paper summarizes the information technology-related research findings after 5 years with the INTROducing Mental health through Adaptive Technology project. The aim was to improve mental healthcare by introducing new technologies for adaptive interventions in mental healthcare through interdisciplinary research and development. We focus on the challenges related to internet-delivered psychological treatments, emphasising artificial intelligence, human-computer interaction, and software engineering. We present the main research findings, the developed artefacts, and lessons learned from the project before outlining directions for future research. The main findings from this project are encapsulated in a reference architecture that is used for establishing an infrastructure for adaptive internet-delivered psychological treatment systems in clinical contexts. The infrastructure is developed by introducing an interdisciplinary design and development process inspired by domain-driven design, user-centred design, and the person based approach for intervention design. The process aligns the software development with the intervention design and illustrates their mutual dependencies. Finally, we present software artefacts produced within the project and discuss how they are related to the proposed reference architecture. Our results indicate that the proposed development process, the reference architecture and the produced software can be practical means of designing adaptive mental health care treatments in correspondence with the patients' needs and preferences. In summary, we have created the initial version of an information technology infrastructure to support the development and deployment of Internet-delivered mental health interventions with inherent support for data sharing, data analysis, reusability of treatment content, and adaptation of intervention based on user needs and preferences.

## Keywords

Adaptive technology, personalized treatments, mental health care, model-based software engineering, human-computer interaction, artificial intelligence, software architecture

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## Introduction

Mental health problems represent a major societal challenge. According to a recent editorial in *Lancet*,<sup>1</sup> almost one billion people worldwide suffer from some form of mental distress, and prevalent mental health problems such as depression and anxiety disorders are affecting up to 15% of the population at any time.<sup>2</sup> Furthermore, mental health problems are associated with substantial costs for the individual, employers, and society. Besides the impact on people's well-being, OECD estimated in 2018 that the total costs of mental illness were above EUR 600 billion – or more than 4% of GDP across the 28 EU countries.<sup>3</sup> The annual costs associated with mental health issues are considerably higher than for other conditions, for example, treatment costs for cancer and ischemic heart disease.<sup>4</sup> The annual treatment costs related to mental health problems have created a strong demand for new innovative ways to deliver mental health care.<sup>5,6</sup> The unmet need for treatment cannot be met by traditional forms of therapy alone, such as weekly individual 50-minute face-to-face sessions, due to limited availability, accessibility and scalability. Moreover, there is a considerable cost for the patient both directly in the form of travelling costs and treatment fees and indirectly since the patient needs to take leave from work, also there is a lack of qualified health personnel<sup>7,8</sup> to meet the need for therapy. To address these problems of accessibility and scalability, there is a need for further research on innovative ways to address these problems. Moreover, this corresponds with the global commitment to respond to UNs sustainable development goals.<sup>1,9</sup> Internet-delivered psychological treatments (IDPTs)<sup>10</sup> are promising means to increase the efficiency and availability of mental health treatments for mild and moderate psychological problems. Emerging evidence shows that current IDPTs can be effective for the treatment of prevalent mental disorders such as depression and anxiety,<sup>11</sup> for these problems has IDPT shown to give similar treatment outcome as face-to-face treatment when guided by a therapist.<sup>12–14</sup> Moreover, in guided IDPT the therapists typically spend 10–20 minutes per week with each patient,<sup>13</sup> hence the therapist can treat more patients. Technology indeed represents opportunities to increase access to health care services and increase the quality of care. Still, the current adoption of IDPTs in mental health care is low, and patient adherence to them is also low.<sup>15,16</sup> Despite the increased popularity of IDPT is the availability in most countries limited or non-existent. To improve the impact of IDPT in mental health care services, we need to develop and evaluate scalable, interoperable and flexible information technology (IT) infrastructures for IDPT. With such infrastructures available, we envision creating engaging interfaces that can adapt psychological treatments according to users needs and preferences. These treatment elements should be standardized such that they could be

shared, adapted and further developed. Furthermore, the infrastructure must handle current regulations regarding privacy, security, availability and performance.

To reach these visions, we need an interdisciplinary paradigm shift<sup>17</sup> from technology as a passive medium for distributing treatment content to using adaptive and scalable technologies to support behavioural change in a highly regulated domain. The INTROducing Mental health through Adaptive Technology (INTROMAT) project has addressed these challenges by establishing an interdisciplinary team including clinicians, researchers in clinical mental health and IT, IT providers, and the software industry. This paper aims at presenting the IT research findings from this project. Within INTROMAT, we have developed interactive and adaptive IDPT technologies using techniques from artificial intelligence (AI), human-computer interaction (HCI), and model-based software engineering (MBSE) to map a patient's mental health across time and place. We have used MBSE techniques and domain-driven design (DDD) to develop flexible, reusable treatment modules and robust, scalable infrastructure for IDPT. In our HCI research, we have collaborated with the end-users by applying user-centred design (UCD)<sup>78</sup> principles in the software and treatment development process to create and evaluate engaging user interfaces, and presentation of treatment elements in a more engaging way. We have developed new machine learning (ML) algorithms and techniques for detecting and classifying patients' behaviour and symptoms. The method has been used to tailor the treatment to individual patients' needs and preferences.

The remaining sections of this paper has the following structure: The Background section presents the background and the motivation for developing adaptive technology to support mental health care. The Methods section describes the method used to develop an infrastructure for creating adaptive IDPT systems by introducing an interdisciplinary work process based on DDD, person-based approach (PBA), and UCD principles. The Results section presents the infrastructure for creating adaptive IDPT systems for routine mental health care and the software artefacts<sup>1</sup> developed in this study. The Discussion section presents and reflects on the findings from this project and their implications. Finally, the Concluding remarks and lesson learned section summaries the principal results and lessons learned from the project.

## Background

This section outlines the background inclined with the project objectives and the problem domain we wish to solve by the presented infrastructure.

### The need for adaptive technology

Currently, most of the available evidence-based online psychological interventions consist of ‘treatment packages’ characterized by uniform composition, intensity, and delivery procedures for all regardless of needs, goals and motivation across potential participants (one size fits all).<sup>79,28,18</sup> Consequently, about 20%–30% of the patients undergoing psychological treatments do not receive therapy that corresponds with their needs.<sup>18</sup> To address this challenge, studies in psychotherapy have investigated ‘what works for whom?’.<sup>19</sup> In IDPT pre-treatment information (e.g., age gender and symptom level) have been extensively studied.<sup>20</sup> Nevertheless, more than 30 years of research has pointed to few consistent pre-treatment factors predicting treatment effects or treatment failures.<sup>21</sup> A more recent approach to the ‘what works for whom?’ question searches for in-treatment factors/mediators/proximal outcomes (such as knowledge acquisition, treatment adherence or engagement with the intervention) preceding distal treatment outcomes, such as reduced symptoms and increased quality of life). The in-treatment and proximal outcomes, such as adherence, may trigger adaptive elements, such as prompts. Non-adherence is frequent in IDPTs, it is not unusual with drop out rates as high as 50%.<sup>22</sup> In INTROMAT we will design adaptive IDPTs to reduce dropout and increase adherence and engagement among patients.

### Research methods for adaptive treatments

In order to study the effects of proximal and distal outcomes, we need to supplement the current randomized controlled trials (RCT’s), the gold standard for studying predefined pre-treatment packages, with ‘Sequential Multiple Assignment Randomized Trials (SMART).<sup>23–25</sup> In SMART, the patients may be randomly presented with adaptive elements multiple times in one trial. The randomization can be based on active or passive data such as symptoms across time or engagement with the program. This approach allows us to study the effects of adaptive treatment strategies on the sequencing of treatment content (psycho-education vs exercises), prompts (frequency), or format (video/audio/ text). The PBA<sup>26</sup> is a method for designing interventions that focus on adapting the intervention to the users’ needs thereby increasing its persuasiveness, feasibility and relevance. It’s focus is on user needs, their contexts, and perceptions of intervention elements in order to promote acceptability, usability, and user satisfaction. The PBA also identifies ‘guiding principles’ that inspire and help the intervention designer to address key context-specific behavioural issues in the intervention.

### Towards a new infrastructure for adaptive IDPT

Current IT-infrastructures for mental health research are primarily developed for health researchers studying the effects

of ‘treatment packages’ using ‘historical’ post-trial data in RCTs. Despite the strong correlation between treatment outcome and user adherence,<sup>16</sup> there are almost no systematic studies available reporting on the usability of the technology of the IDPTs.<sup>27</sup> Furthermore, there is also a lack of studies systematically collecting and analysing user data to investigate possibilities for implementing IDPTs that can better respond to the needs of each user.<sup>28</sup> Hence, by using the existing IDPT infrastructure, it is almost impossible to implement and evaluate the principles of SMART and PBA.

In order to facilitate for intelligent use of data during RCTs and online treatments, there is a need for infrastructure with the following characteristics:

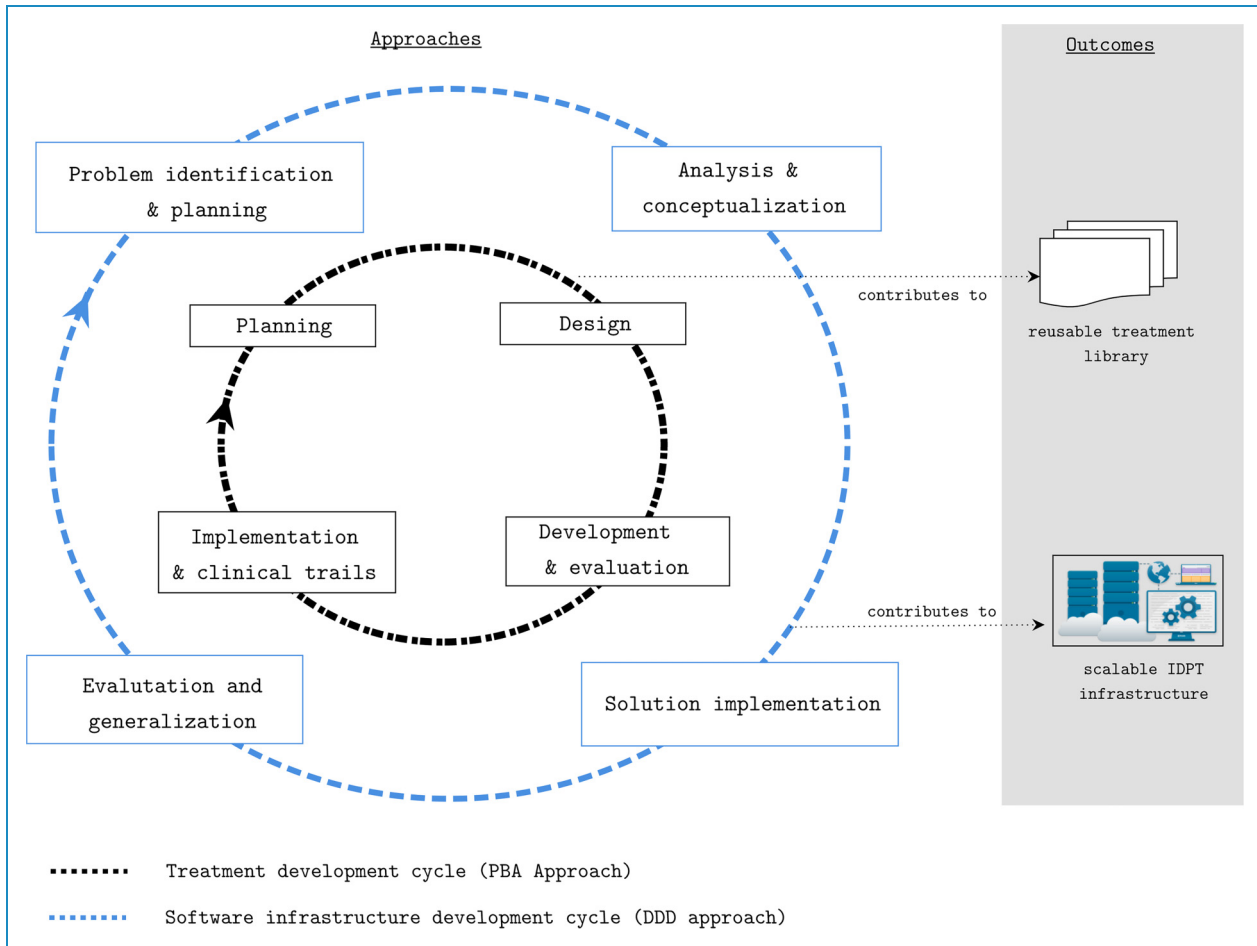
- The infrastructure should incorporate powerful analytic tools that can collect, store, analyse and feed data back to the user at the right time and in appropriate formats.
- The infrastructure should support state-of-the-art capabilities from ML, HCI and MBSE. In addition, it allows us to perform clinical research on adaptive treatments in the mental health care domain.
- The infrastructure within routine mental health care must support the ecosystem of service providers where health care providers, collaborating partners and independent developers can design, provide, and reuse the best possible services within a reliable and secure environment.

### Methods

In INTROMAT,<sup>29</sup> the adaptive software infrastructure was developed through tight interdisciplinary cooperation within the following seven clinical cases.

1. Early intervention and treatment for social anxiety disorder in VR-based exposure for adolescents with fear of public speaking,<sup>30</sup>
2. psycho-social support for women after gynaecological cancer,<sup>31</sup>
3. cognitive remediation of residual cognitive symptoms after major depressive disorder,<sup>32</sup>
4. internet-delivered depression treatment in standard care,<sup>33</sup>
5. internet delivered training program for adults with an ADHD diagnosis,<sup>34</sup>
6. relapse prevention and early detection for bipolar disorder,<sup>35</sup> and
7. coping with distress related to COVID-19.<sup>36</sup>

The cases listed above represent self-help and guided treatment in primary and secondary health care services. The cases involve age groups from adolescents to older people with primary psychiatric and somatic disorders. In order to develop the infrastructure required to provide adaptive treatments to these patient groups, we needed to align



**Figure 1.** The figure illustrates our methods for creating IT infrastructure for developing adaptive IDPT for routine mental health care. The inner loop shows the treatment development cycle using the PBA. The outer circle represents the software infrastructure development cycle using the DDD approach. IT: information technology; IDPT: internet-delivered psychological treatment; PBA: person-based approach; DDD: domain-driven design.

our development steps according to the psychological treatment cycle. Figure 1 illustrates the correlation between steps involved in creating psychological treatments using the PBA<sup>26</sup> with a software development approach using DDD.

PBA is a method for designing mental health interventions. It complements traditional treatment approaches by capturing and incorporating user perspectives as part of the design process. Furthermore, PBA borrows techniques from UCD, such as from behavioural analysis and qualitative research methods, to incorporate both digital and non-digital behavioural aspects of interventions.<sup>28</sup> DDD is a software development process that advocates that it is essential to comprehend any problem before creating a solution. An inadequate and distorted understanding of the problem results in a faulty and non-useful solution. Hence, it advocates involving domain experts in the software development cycle.

As depicted in Figure 1, the PBA approach for developing psychological interventions for mental health problems involves: (a) planning, (b) design, (c) development and

evaluation of acceptability and feasibility, and (d) implementation and trials. Similarly, the software infrastructure development cycle involves (a) problem identification and planning, (b) analysis and conceptualization, (c) solution implementation and evaluation with testing, and (d) generalization and infrastructure inclusion along with infrastructure extension. Both the treatment and software development cycles are iterative and involve the continuous enhancement of artefacts produced from the evaluation process. Traditionally has technology been developed by software engineers after the interventions has been developed by clinical researchers in IDPT. The technology is viewed as means to deliver the intervention. Our experience is that by aligning the technology development with the intervention design we could improve both the intervention design and the supporting technologies by:

- Better utilizing the technology opportunities in the design of the intervention.

- The software will support the goals of the researchers.
- Necessary data values for adaption of the intervention will be included in the software.

## Results

We present the reference architecture (RA) as a central artefact of this study. The RA, depicted in Figure 2, illustrates the infrastructure for creating an adaptive, interoperable and reusable IDPT system for routine mental health care. This section outlines the proposed RA for obtaining a scalable infrastructure for building adaptive IDPT in routine mental health care (Reference architecture section) and technological considerations for building such an infrastructure (Technical architecture considerations section).

### Reference Architecture

The proposed RA is based on the study presented in the work of Mukhiya et al.<sup>37</sup> As shown in Figure 2, the architecture consists of four different layers: consumer architecture, requirement architecture, technical architecture, and artefacts produced in the INTRMAT project.

**Consumer architecture.** It represents the end-user context that influences the technical solution. Depending on countries and their health care services, consumer contexts vary based on the legal services, the need for privacy, quality of services, governance and policies, and other contexts.

**Requirement architecture.** It represents which built-in qualities the infrastructure should support. The primary software quality attributes required in IDPT systems are scalability, interoperability, adaptability, security, privacy, performance, availability, re-usability and modifiability.

**Technical architecture.** It represents how we can realize the psychological treatments in routine clinical health care within the software development cycle. As depicted in Figure 2, this layer consists of the following four sub-layers:

1. **End-user layer.** This layer consists of sensor devices for capturing biomarkers such as Empathica E4 for capturing electro-dermal activity; smartwatches for heart rates, activities, and other health data; VR applications for head movement and voice data; Oura Ring for sleep data and others.
2. **Terminal layer.** The data from the end-user layer are sent to the terminal layer by using Local-Area Networks such as ZigBee protocol, Bluetooth, GSM, or WiFi. It generally includes Smartphones. However, a laptop or a computer can act as a terminal layer.
3. **Application layer.** The data from the terminal layer are sent to the application layer using Wide Area Network protocols involving Web Services such as RESTful communication. The application layer involves one or more application

services communicating over service-oriented architecture (SOA) such as CMS applications, authorization servers, dashboard applications, and other third-party applications.

4. **Analytics layer.** The data from the application layer are sent to the analytics layer using RESTful communication. This layer involves advanced computational services like AI, ML, Deep Learning, Pattern recognition, Natural Language Processing (NLP), data mining and other cognitive services. For example, when patients interact with an intervention, they may write some texts as a part of computerized exercises. These texts exhibit keywords that express the current state or emotion of the patient. It is possible to send these texts directly to available NLP application programming interface (APIs) such as Google NLP<sup>2</sup> and get the sentiment of the text, tone of the texts, and detect the presence of depression-related keywords.<sup>38</sup> In previous studies,<sup>38,39</sup> we demonstrate how we can exploit the NLP technique to extract depression symptoms from such patient-authored texts.

### Library of reusable IDPT content:

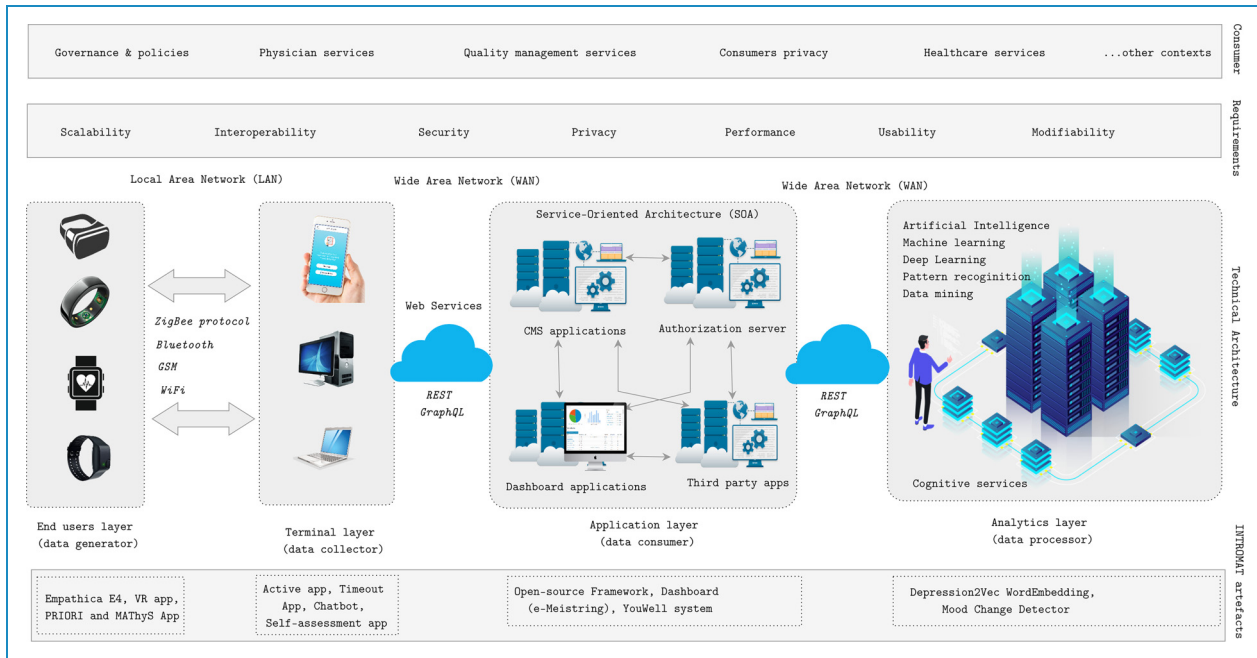
During the INTRMAT project, we developed and validated seven IDPT interventions (see Methods section). Initially, the interventions were built as isolated IDPTs by different teams of experts in psychology and IT. During the project, we experienced the need for reuse and modification of existing treatment components. Hence, we developed a library of IDPT intervention contents to fetch interventions, their modules, and their tasks. The library is accessible through an API. A critical purpose is to facilitate the extraction of treatment materials such that content can be accessed from different platforms, such as web applications or mobile applications. In the work of Fuglestad<sup>40</sup> we demonstrate a dimensional modelling approach to the ontological organization of IDPT components based on the user profiling dimensions of the open IDPT framework. We focused on two use cases for this approach, namely (a) facilitating reuse of treatment materials and (b) adapting existing treatment materials to user needs.

### Artefacts produced

The last layer maps the artefacts produced with the RA. The artefacts are listed in Table 1. The primary idea is to list the artefacts and map them into the proposed RA. Interested readers will find the problem these artefacts solve, the study method, results and evaluation process of each of these artefacts in the studies referred to. We briefly introduce the clinical setting of these artefacts below (the index represents the row number in Table 1):

1. **Timeout App (ADHD):** This study uses the Empatica E4 wearable to capture physiological signals to





**Figure 2.** Reference architecture for creating adaptive intervention in routine mental health care. The top layer presents *consumer architecture*, the second layer presents *business architecture* requirements, the third layer presents *technical architecture* and the last layer outlines the artefacts produced in INTROducing Mental health through Adaptive Technology (*INTROMAT*) project.

monitor arousal levels in adults with ADHD. The IBM Cloud was used to preprocess the captured data and to produce timely prompts to deliver skill-building exercises to the participants.<sup>41</sup>

2. **VR App (Social Anxiety):** A custom-built VR stimuli exposure application for adolescents in the age of 13–16 with fear of public speaking was designed as a classroom featuring virtual avatars. The avatar was in the same age group as the users, and they provided body animations and gazed directed at the user. A high-end VR headset was used for stimuli presentation. The user behaviour was automatically logged by the application (e.g. when the user was entering and exiting the classroom) with timestamps.<sup>30</sup>
3. **Motor activity monitor (Bipolar Disorder):** In this study, we used machine-learning techniques to investigate if objective measures of motor activity can aid existing diagnostic practice by analysing activity patterns in depressed patients and healthy controls. Our findings indicate that analysing motor activity time series with machine-learning techniques present promising abilities to discriminate between depressed patients and healthy controls,<sup>42</sup> as well as differentiating between manic and asymptomatic bipolar patients.<sup>43,44</sup>
4. **Self-assessment chatbot (ADHD):** In this study, we developed a chatbot for screening symptoms for ADHD in adults based on the psychometric questionnaire Adult ADHD Self-Report Scale (ASRS). In the study, we compared the responses from the conversational chatbot with responses on the standardized paper-

based ASRS. Furthermore, in the study, we also evaluated the user interaction with the chatbot. The results indicated similarity between the two modalities in the screening process.<sup>45</sup>

5. **Dashboard (Depression):** A dashboard with visualizations of patient activity, to be used by therapists in guided, online Internet-based treatment for increasing the therapists awareness of their patients needs for support and symptom development. We studied its usefulness by conducting workshops and interviews with domain experts, end-users and clinicians.<sup>46,47</sup> Our study demonstrates a need for interactive tools to visualize actual care processes being executed in the hospital. A tool visualizing real-time data could give a dynamic view of the processes with accurate quantitative information, improving the quality and efficiency of health care provision. We also illustrated how a model-based approach was used to develop a library of reusable visual components.<sup>47</sup>
6. **OpenIDPT Framework:** We proposed a software framework for developing adaptive, reusable, and interoperable Internet-Delivered Psychological Treatments (IDPT), referred hereto as the *OpenIDPT Framework*.<sup>48</sup> The OpenIDPT Framework includes (a) a Reference Model (RM), (b) a Reference Architecture (RA), (c) an Information Architecture (IA), and (d) an open-source implementation of an adaptive IDPT system. The *RM* reveals the adaptive elements (what to adapt), adaptive dimensions (on what basis to adapt), information architecture (how to structure content), and strategies (how to

**Table 1.** A list of software artefacts that have been developed in the INTRMAT project.

Index	Artefacts	Aim	Technology	Data Store/Share	Research Contribution
1	Timeout App (ADHD)	To monitor arousal levels in adults with ADHD and use the data to deliver timely prompts to perform a skill-building exercise.	Empatica E4 wearable wristwatch was used to capture real-time physiological signals.	Data captured from wearable devices were sent to IBM cloud for processing via Telenor Shepherd Internet of Things (IoT) infrastructure.	A moving average algorithm was developed to detect significant changes in arousal and send alerts to patients. <sup>41</sup>
2	VR App (Social Anxiety)	To create an in vitro home-based exposure scenario for adolescents with fear of public speaking.	A VR app and Empatica E4 were used to capture patient's physiological signals during the VR therapeutic intervention.	Data captured from sensor devices were normalized and sent to data analytics in the Weka framework.	ML were applied to detect correlation of stress with physiological signals. <sup>60</sup> Participatory design was applied to design VR scenarios. <sup>41</sup>
3	Motor activity monitor (Bipolar Disorder)	To monitor motor activity with the long-term goal to early detection of new manic and depressive phases.	Actigraph watch was used to capture bipolar patients' motor activity signals on a daily basis.	14 days of motor activity data from 23 depressed patients and 32 healthy controls were captured and analysed in the Weka framework.	Different ML algorithms were applied to analyse the actigraph data to predict significant mode change. <sup>42,61</sup>
4	Chatbots for: 1) Self-assessment and 2) Group therapy (ADHD)	1) To provide self-assessment for adults with ADHD and 2) To investigate if chatbots for peer support in ADHD group therapy.	1) A chatbot was used to capture ADHD symptoms. 2) A low fidelity chatbot prototype was used for capturing user experience data	1) Chatbot data were sent to IBM Watson for analysis. 2) UX data from test and control group were collected and analysed in IBM Watson.	1) IBM Watson was used for detecting ADHD symptoms in chatbot data. <sup>45</sup> 2) Rtd applied to investigate if chatbots could facilitate peer support among adults with ADHD. <sup>62</sup>
5	Patient dashboards for therapists (Depression)	To support therapists in guided IDPT to manage their work, and understand and prioritize their patients.	A dashboard was developed to present a generated view of patients' treatments and interaction data to support therapist's interaction with the system.	Data from the clinic management system and self-assessments are used for real-time presentation of patients' interaction and symptom development.	IDPT treatment patterns was identified and represented by time series, interactive spider charts introduced, <sup>46</sup> further reusable visual components presented <sup>47</sup>
6	OpenIDPT Framework	To create an open-source framework for building adaptive IDPT System.	A web application framework is created that can be extended and used for several similar health care cases.	It collects user profile data to personal adaption of interventions. Data are available in HL7	Adaptation strategies can be decided by the therapists or an analytical server can be integrated for adaptation. <sup>48,37,28</sup>

(continued)

Table 1. Continued.

Index	Artefacts	Aim	Technology	Data Store/Share	Research Contribution
				FHIR and GraphQL format.	
7	Self-assessment App	To provide self-assessment for adults with mental health	A mobile application that provided psychometric questionnaire in HL7 FHIR format	Data captured from the mobile application was delivered using HL7 FHIR format for further study.	The open-source app can be used to build any self-assessment questionnaire and supports interoperability. <sup>49</sup>
8	Gynea intervention (Cancer Survivors)	To design IDPT targeting women's psycho-social needs during the follow-up period after treatment for gynecological cancer	Internet intervention including psycho-educational information, multimedia content, exercises, and weekly follow-up with a nurse	Semi-structured interviews was applied to evaluate the patients experience of the audiovisual narratives.	User Centered Design (UCD) <sup>78</sup> was applied to create audiovisual narratives to support reflection on cancer journeys <sup>50</sup>
9	PRIORI and MATHyS App (Bipolar Disorder)	To collect mobile phone speech data from regular calls by out of hospital bipolar patients and analyse them to detect mood changes.	The PRIORI mobile phone app collects speech data from regular calls by out of hospital patients, and the MATHyS web app is used to collect weekly self-reports from PRIORI app users.	The PRIORI and MATHyS data were forwarded to the 'Services for sensitive data' (TSD), a secure data storage at the University of Oslo, the data were made available for data analytics	The MATHyS data will be used to label the speech data collected by the PRIORI app. <sup>52</sup> The labeled data will be used to train models to estimate the mood by classifying the speech data <sup>51</sup>

INTROMAT: INTROducing Mental health through Adaptive Technology; IDPT: internet-delivered psychological treatment; PRIORI: Predicting Individual Outcomes for Rapid Intervention; MATHyS: Multidimensional Assessment of Thymic States.

adapt) of an adaptive IDPT system.<sup>28</sup> The RA<sup>37</sup> unveils the technical architecture of an adaptive IDPT system. The *information architecture* guides how to structure and organize the content for better discoverability and comprehensibility. To evaluate the proposed RA of adaptive IDPT systems, we implemented a prototype as an Open-Source Software. We refer to this prototype as *Open-Source Adaptive IDPT System*. Our preliminary results demonstrate that the proposed artefacts exhibit capabilities to use comprehensive user profiling techniques to adapt interventions. Such adaptation can involve several strategies, including AI, recommendation systems, or rule-based engines.<sup>38</sup>

7. **Self-assessment app:** This study developed a mobile terminal app for providing self-assessment associated with several mental health illnesses. These assessments were supplied as a psychometric questionnaire in HL7 FHIR format. The app introduces an HL7 FHIR based format for standardized and reusable psychometric questionnaires, which intend to increase interoperability among IDPT applications.<sup>49</sup>

8. **Gynea, online intervention (Cancer survivors):** In this study, we developed an Internet-delivered intervention for addressing the psychosocial needs of gynaecological cancer survivors.<sup>31</sup> The intervention, which is to be evaluated through a clinical study, was designed to increase the quality of life for women who had survived gynaecological cancer by providing means to cope better with daily life after cancer treatment. In the article,<sup>50</sup> we present and discuss how three audiovisual narratives for the online intervention were designed based on a broad evidence base, a solid theoretical foundation, and through an experience-centred design process in close cooperation with gynaecological cancer survivors.

9. **PRIORI and MATHyS APP (Bipolar disorder):** In this study, we investigated how speech data could predict the mood of patients with bipolar disorder. An app for Predicting Individual Outcomes for Rapid Intervention (PRIORI) was developed.<sup>51</sup> The app collects phone call speech data from regular calls by out-of-hospital persons with bipolar disorder. The app



has been developed in the US, but we ported it in order to be able to store the collected data in a safe domestic server.

The Multidimensional Assessment of Thymic States (MATHyS) app is a web application where users report every week how they are currently feeling. The app is applied to collect weekly self-reports from PRIORI app users and label their speech data. A mood state score is computed using the data and applied to label the speech data provided by the corresponding person. The PRIORI speech data, together with the MATHyS score, is intended to be used to train a classification model that can be used for monitoring the mood of its users (distinguish between euthymic (healthy), depressed and manic states).<sup>52</sup>

### Technical architecture considerations

This section outlines the technical considerations that we advocate as a requirement for building adaptive and scalable infrastructure in routine mental health care.

**Service orientation.** Data services are at the core of any modern software infrastructure, providing services related to storing and retrieving data. Such services include storing and accessing data in specific formats, giving access to different abstraction levels, retrieving data about particular types of entities, batch uploading of data, and others. Services are made available through APIs based on standardized exchange formats, models and terminology. These services are vital for interoperability that is a fundamental necessity for the successful realization of Health care Information Systems.<sup>53,54</sup> We can achieve interoperability by following established standards such as HL7 FHIR, which supports Representational State Transfer (REST) architecture and SOA for seamless information exchange. However, it inherits the inflexibility and complexity associated with the RESTful approach.<sup>53</sup> GraphQL is a query language developed by Facebook that provides promising techniques to overcome these issues. In the studies,<sup>53,55,56</sup> we exploit the use of GraphQL and HL7 FHIR for Health Information Exchange (HIE), present an algorithm to map HL7 FHIR resources to a GraphQL schema, and create a prototype implementation of the approach, and compare it with a RESTful approach. Our experimental results indicate that the combination of GraphQL and HL7 FHIR-based web APIs for HIE has better performance, is more cost-effective, scalable, and flexible to meet the web and the mobile clients' requirements.

Health care information from various disciplines needs to be harmonized for analysis.<sup>54</sup> Ontologies provide vocabularies to integrate data from multiple health care information systems. In the INTRMAT project, we used

SNOMED-CT and ICD-10 ontologies to add semantics to the data captured from sensor devices and mobile applications. The use of standard health care ontologies enables the interoperability of our systems. It helps us to perform data mining operations over multiple data sources. Ontologies could also be applied to present and analyse health care information from numerous viewpoints (for example, contexts) such as patient demographic, specific diseases, incidences of co-morbidity, type of health care service setting (for example, clinic, hospital, nursing home), home location (urban or rural), and others.

Process mining techniques hold great potential to support health services by identifying inefficiencies and scope for improvement.<sup>57,58</sup> However, traditional process mining techniques have limited support for searching after and presentation of process information at different levels of abstraction. Hence in the work,<sup>59</sup> we proposed a model-based slicing approach based on dimensional modelling and ontological hierarchies that can raise the level of abstraction during process mining, thereby more effectively dealing with the complexity and other issues in IDPT.

**User interfaces.** The infrastructure provides user interfaces for ordering and managing subscriptions to infrastructure services (treatment content, therapist support), support applications for a level of data access (for example, symptom levels), recruitment of research subjects, documentation of consent, publication of surveys, data explorers, visualization tools (for example, a dashboard for patient or therapist), and others. The infrastructure also supports the use of sensors and smart devices to gather data and communicate with patients. Both managed and unmanaged devices might be used, giving differentiated access to the infrastructure based on the security level of the specific devices and the specific use cases. Some data might be freely available through open APIs. In contrast, other data types will be very restricted or completely inaccessible externally.

A common need among the therapists involved in guided internet-based treatment is to gain insight into a group of assigned patients. The therapists need to gain information from looking at a higher level of abstraction for various purposes, including prioritizing their patients for follow up. This requirement can be addressed through a dashboard where information from various perspectives is accumulated to indicate areas that require attention. We performed a study among the therapists from a specialist care clinic where guided internet interventions are offered as part of routine care. The system needs exploration revealed three main categories of therapists needs:

1. A tool to prioritize which patient to help first;
2. A tool to monitor the progress of individual patients within the therapy; and

3. A tool to monitor the time and effort spent by the therapist on each individual patient during the therapy trajectory.

In,<sup>46</sup> we presented a dashboard that gives the therapists an overview of the change in psychometric variables both for individual patients and groups of patients. In the work,<sup>47</sup> this was further developed to a model-based approach for visual analytics by using model-based artefacts such as ontology, dimensional models, and meta-models. It was presented how these artefacts could be composed to construct reusable visual components. Using the model-based approach for visual analytics could bring several benefits, such as reduced cost, better support for customization, and the possibility for defining user-specified groups of patients with the support of aggregated analysis of these groups.

*Data processing and analytics.* Data processing in IDPT brings the potential to deal with mental illness more flexibly and adaptively and still decrease the need for human resources. In the INTROMAT project, data are collected from many different sources; in addition to data from the EHRs, we collect data from user input by self-reporting psychological questionnaires, activity data from sensors available in smartphones and wearable devices, interaction data are collected when a user is following an Internet-delivered treatment program, and more.<sup>63</sup>

These data need to be of high quality and sufficiently annotated to successfully apply machine learning techniques to:

- train models to make estimates of the current and future mental state of a person,
- make a prognosis about how successful intervention is expected to become,
- provides personalized adaption of a treatment program with regard to when what and how material and/or interactions are being presented to each individual user.

However, we would not like to repeat this process for each new user. Thus, it is crucial to reduce retraining of the ML models as much as possible, for example with transfer learning.<sup>64</sup>

We presented a study over a dataset containing motor activity of depressed and non-depressed participants to perform depression classification using machine learning.<sup>65</sup> The motor activities of a healthy control group and a condition group were monitored with a wearable sensor device (actigraph watch). We used the public dataset that is available at <https://goo.gl/5Aevg5>.<sup>61</sup> In the study, we applied classification methods which included Random Forest and a Deep Neural Network approach. Also, we presented a comparison of several data balancing techniques. The overall findings indicated that the motor activity sensor

data could be used to determine the depression status of a person.<sup>65</sup>

*Data integration and exchange of data.* The INTROMAT software infrastructure is directed both at clinical research and delivery of treatment services to end-users. Several of the IDPT services produced in the INTROMAT project are already available as part of the Norwegian national online health services. Hence, integration with clinical and other core systems is a crucial objective. The platform will allow for bidirectional integration with clinical systems by developing APIs to make data available and allow different data providers for some types of information. Integration with clinical systems will be strictly regulated. The INTROMAT software infrastructure will facilitate external sources of information and resources available in other available research infrastructures. International resources may also be used. For some types of information, the infrastructure will integrate with external master data sources. Where national resources or international master data sources are available and agreed upon, integration may be done as a shared infrastructure resource. If regional sources must be used, different data providers might be facilitated in the integration layer.

Many health care scenarios are so complex that they involve multiple systems. Hence bidirectional synchronization and integration will not be enough to capture all possible scenarios. To handle such rich complexity, we introduced a comprehensive system in the work of Stunkel et al.<sup>66</sup> A comprehensive system allows us to express and reason about synchronization and integration of multiple health information systems.

## Discussion

In this section, we summarize and discuss some fundamental considerations that must be taken to deliver adaptive IDPT systems. In addition, we discuss the impact of artefacts produced in the INTROMAT project and the primary lessons learned during this interdisciplinary project.

### *Handling of privacy and security*

Privacy and security are of the highest importance when working with any health data, particularly within the domain of mental health. In the INTROMAT project, the clinical research trials had to get approval from the regional ethical committee for health research and follow the required ethical research standards. Moreover, the infrastructure should implement the state of the art techniques for privacy and security.

Due to the tight integration of actual treatment with interventions and the sensitive nature of the information involved, it is required to apply a structured approach to

information management to maintain a high level of security throughout all infrastructure. Providing all services needed to research projects within one environment enables us to ensure adequate security without significantly restricting the freedom of interdisciplinary research initiatives. The following capabilities are vital to ensure privacy and security in such an environment:

1. **Authentication:** Authentication and access control is performed for all users trying to access resources within the infrastructure. The authentication layer supports external users with identities administered by third parties and national authentication services. According to Norwegian law, users must provide at least two authentication factors to acquire system access. All IoT devices, such as medical devices and wearables, have to be authenticated to access the infrastructure. An automated process will handle the registration of new IoT devices.
2. **Authorization:** The access control layer handles authorizations and policy management for different user groups. All IoT devices must be authorized before they can submit data to the infrastructure. Other hosting environments will integrate with the infrastructure, but authentication and authorization will also be enforced for services running on external servers.
3. **Logging and tracking:** This will be performed on all layers in the infrastructure, including access from both internal and external users. Automated pattern recognition tools will be used to identify suspicious behaviour.
4. **Privacy services:** We must provide standard services for privacy in compliance with GDPR and the Code of Conduct. These services will ensure that the access control policies cover all users of the infrastructure and all available resources. The policies will be set in compliance with the classification of the resources and the needs of the users. Different policies will apply for different categories of users, for example patients, clinicians, developers and research personnel. Additional security measures will be implemented to mitigate the risks of unauthorized access to personal information and health data. An encryption service will be an essential measure to protect data in the infrastructure. With strict access control on all architecture layers, encryption will play a central role in the multi-layered security approach of the infrastructure.

Data analysis of health data provides valuable information to individuals and medical experts. For conducting data analysis, the main requirement is the data itself. However, the required data are often stored across various sources, for example, hospitals or patients' devices. To extract relevant information, the use of the data stored on different sources is essential. Nevertheless, this should not compromise the privacy of the patients since privacy is among the fundamental

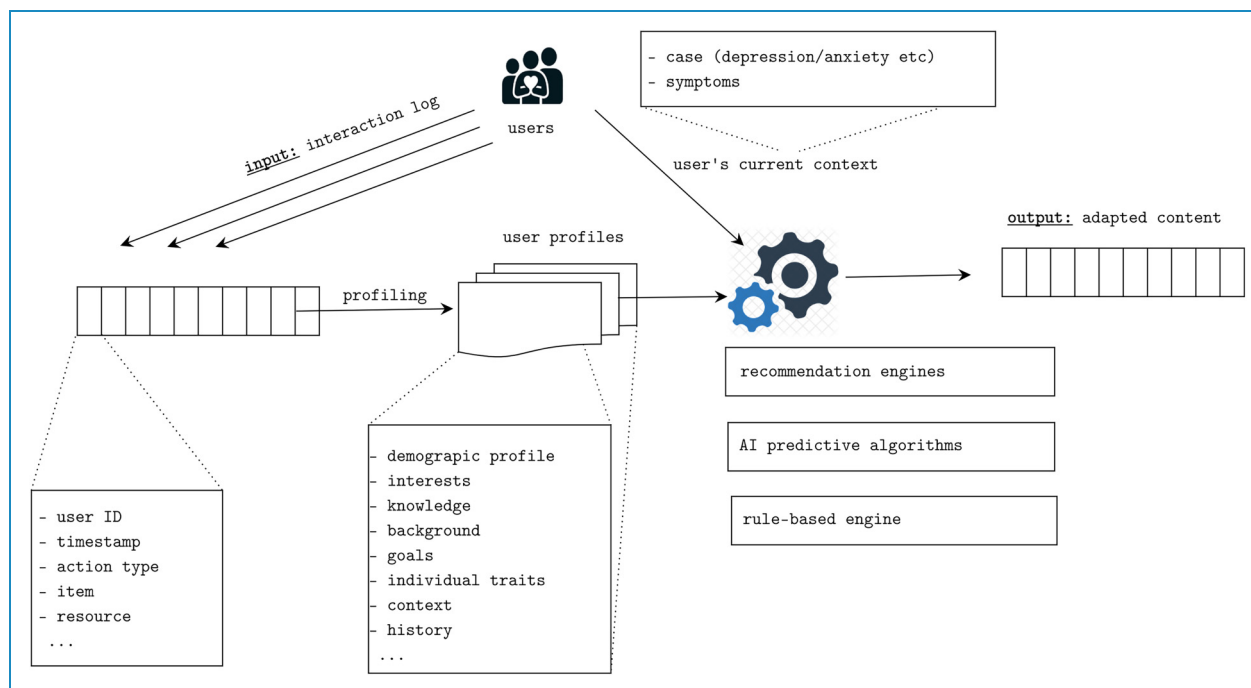
components of the infrastructure of health care systems. Consequently, we had to extend the state-of-the-art knowledge by developing new data analysis frameworks to analyse such distributed data without any privacy violation.

There are two different approaches regarding privacy-preserving data analysis. In the first alternative, the (processed) data are shared in a central location. However, we need to take the necessary measures to preserve the patients' privacy in the dataset. This approach is generally known as privacy-preserving data sharing. Perturbation-based techniques, along with anonymization approaches, propose solutions for privacy-preserving data sharing, for example,<sup>67-71</sup>. However, the trade-off between privacy and data utility in such approaches renders them impractical in many applications.

In the second alternative, we conduct privacy-preserving data analysis without sharing the data, for example, in the literary works.<sup>72-76</sup> Several mining algorithms can learn machine-learning models by receiving partial information about the data in the learning process instead of raw data. The party/parties holding data can participate in the learning process by merely sharing partial information instead of the raw data. Moreover, specific approaches adopt secure multi-party computation techniques for limiting the sharing of partial information. Hence, such techniques provide solutions for mining without sharing data or sensitive information and, consequently, preserve data subjects' privacy. Privacy-preserving distributed machine learning approaches address the learning tasks without sharing the data while preserving the patients' privacy.

### Adapting interventions

We aim to deliver adaptive interventions based on the patients' needs and preferences and in the context of any given situation. To do this, we need to create an adaptive IDPT system that can personalize psychological treatments based on a patient's needs, contexts and preferences. An adaptive system needs to have a detailed profile of users to comprehend their status, requirements, contexts and priorities. User preferences, progress and needs are dynamic. Hence, it is essential to create, maintain, and update the user model. An adaptive system accumulates the user model data into two distinct approaches: (a) implicitly by observing user interactions and (b) explicitly requesting direct input from the user. This process is referred to as user profiling. The essence of the adaptation effect that a system can deliver depends on the user model's information. A comprehensive profile is a primary basis for adapting an intervention in an IDPT context. Figure 3 adopted from the study<sup>48</sup> depicts why user profiling is essential for creating adaptive content. Users interact with the intervention system and generate a large number of interaction logs. The analytics server stores, analyses, and processes these interaction logs to create a comprehensive user profile. Major user profile components include interests,



**Figure 3.** The figure depicts why user profiling is essential for creating adaptive content.<sup>48</sup>

knowledge, background, goals, individual traits, user context, user history and other demographic data.<sup>37</sup> These user profiles serve as input for recommendation engines, AI-based predictive algorithms, and rule-based engines to create adapted content. Once a user profile is maintained, we can adapt content using several predictive algorithms, recommendation engines, or rule-based engines.

User profiling, as aforementioned, could be built explicitly by asking the patients or using implicit interaction log data. For example, the analytics layer, as depicted in Figure 2 uses several AI-based approaches to extract user profile information.

### Concluding remarks and lesson learned

In our previous work,<sup>77</sup> we identified six challenges in interdisciplinary research projects:

1. To develop a shared understanding of the domain.
2. To establish a common understanding of key concepts among the participants of the project.
3. To involve the end-users in the research and development process
4. To collaborate across sectors.
5. To ensure privacy and security.
6. To obtain the right timing of activities.

We also envisioned some possible organizational solutions to these problems. In this paper, we have further refined and formalized these findings and introduced a work process

that builds on principles from UCD and aligns the work cycles for PBA to the treatment development with the DDD software infrastructure development. This model directly addresses challenges 1,2,3,4, and 6 above.

Also, we have presented a reference infrastructure for IDPT, including how privacy and security are handled in the infrastructure (challenge 5). Moreover, we presented an open-source reference implementation of the infrastructure, a library of reusable IDPT treatment elements, and a set of developed artefacts and how they are connected to the infrastructure. Finally, we presented the main research findings performed in the INTROMAT project in MBSE, AI and HCI. In INTROMAT we have started the development of an infrastructure to design, develop and deploy internet-delivered mental health interventions with the capability of data sharing, data analysis, and reuse and adaptation of treatment content.

### Topics for future research

IDPT is still an emerging technology where, until now, the development has mainly been driven by health care practitioners in cooperation with the IT industry. In the INTROMAT project, we have experienced how MBSE, HCI and AI research can be used to improve today's IDPT systems. We envision further research potentials in the IDPT domain and propose the following problems as candidates for future research:

- *More efficient data sharing and collaborations:* We have experienced that treatment data are locked down

in the current IDPT systems and not available for data analysis and ML. Hence, there is a need for timely privacy-preserving data sharing and data analytics to adapt the IDPT systems to the users' needs.

- **Reuse and adaption of interventions:** Clinicians or researchers in mental health have designed today's IDPT systems mainly to deliver one specific intervention. To obtain reusable treatment elements, we need to introduce domain modelling in IDPT. Moreover, to give personal adaptations based on the users' needs in various contexts, we need to establish standardized measures over user profiles such as preferences, engagement, background and adherence.
- **The development process:** It will be beneficial to establish an iterative IDPT development process starting with low fidelity prototyping, which is further refined and moves on to testing in controlled laboratory trials and finally studying effects using complete clinical trials with user participation from actual patients and therapists. The process should include establishing evaluation criteria for the treatment effect, software quality, and usability.
- **Facilitate active user involvement:** Several of the applications and artefacts developed through INTROMAT were developed in close interaction with users or user representatives. Initiatives to involve users throughout the development process were carried out to ensure high ecological validity, relevance and utility of the applications. This is in line with recommendations both from the field of HCI and the method of PBA. User involvement in design often involves *consulting* the user, for example in terms of preferences/user studies pre-development, and gathering feedback about usability post-development. Within the field of digital mental health we see it as a research challenge to increase the scope of user involvement, going beyond consultation, and finding ways for participants to contribute as designers. This involves development and refinement of the current methods in use.
- **Explainable AI (XAI):** We have shown examples of how AI and ML can be utilized in IDPT systems to adapt interventions. However, to fully benefit from these techniques, clinicians must understand the rationale of the AI predictions. Hence, there is a need to develop more XAI techniques so that the algorithms used to predict relevant content for patients are well justified, and the process behind the output is transparent to the user.

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## Notes

1. An artefact is one of many tangible by-products produced during the development of software.
2. <https://cloud.google.com/natural-language>

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