Conversational Agents as Mediating Social Actors in Chronic Disease Management Involving Healthcare Professionals, Patients, and Family Members

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Abstract

Background: Successful management of chronic diseases requires a trustful collaboration between healthcare professionals, patients, and family members. Scalable conversational agents (CAs), designed to assist healthcare professionals, may play a significant role in supporting this collaboration in a scalable way by reaching out into the everyday lives of patients and their family members. Until now, however, it has not been clear whether CAs, in such a role, would be accepted and whether they can support this multi-stakeholder collaboration.

Objective: With asthma in children representing a relevant target of chronic disease management, this work has two objectives: (1) To describe the design of MAX, a CA-delivered asthma intervention that supports healthcare professionals targeting child-parent teams in their everyday lives; (2) To assess the (a) reach of MAX, (b) CA-patient working alliance, (c) acceptance of MAX, (d) intervention completion rate, (e) cognitive and behavioral outcomes, and (f) human effort and responsiveness of healthcare professionals in primary and secondary care settings.

Methods: MAX was designed to increase cognitive skills (i.e. knowledge about asthma) and behavioral skills (i.e. inhalation technique) in 10-15-year-olds with asthma and enables support by a health professional and a family member. To this end, three design goals guided the development: (1) To build a CA-patient working alliance; (2) To offer hybrid (human- and CA-supported) ubiquitous coaching; (3) To provide an intervention with a high experiential value. An interdisciplinary team of computer scientists, asthma experts, and young patients with their parents developed the intervention collaboratively. The CA communicates with healthcare professionals via email, with patients via a mobile chat app and with a family member via SMS. A single-arm feasibility study in primary and secondary care settings was conducted to assess MAX.

Results: indicate an overall positive evaluation of MAX with respect to its reach (49.5% (49 out of 99) of recruited and eligible patient-family member teams participated), a strong patient-CA working alliance, and a high acceptance by all relevant stakeholders. Moreover, MAX led to improved cognitive and behavioral skills and an intervention completion rate of 75.5%. Family members supported the patients in 269 out of 275 (97.8%) coaching sessions. Most of the conversational turns (99.5%)

were conducted between patients and the CA as opposed to between patient and healthcare professional, thus indicating the scalability of MAX. In addition, it took healthcare professionals less than four minutes to assess the inhalation technique and three days to deliver that feedback to the patients. Several suggestions for improvement were made.

Conclusions: For the first time, this work provides evidence that CAs, designed as mediating social actors involving healthcare professionals, patients and family members, are not only accepted in such a "team player" role, but also show potential to improve health-relevant outcomes in chronic disease management.

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Abstract

Background: Successful management of chronic diseases requires a trustful collaboration between healthcare professionals, patients, and family members. Scalable conversational agents (CAs), designed to assist healthcare professionals, may play a significant role in supporting this collaboration in a scalable way by reaching out into the everyday lives of patients and their family members. Until now, however, it has not been clear whether CAs, in such a role, would be accepted and whether they can support this multi-stakeholder collaboration.

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Conclusion: For the first time, this work provides evidence that CAs, designed as mediating social actors involving healthcare professionals, patients and family members, are not only accepted in such a "team player" role, but also show potential to improve health-relevant outcomes in chronic disease management.

Keywords: Digital health intervention; intervention design; mHealth; eHealth; chatbot; conversational agent; chronic diseases; asthma; feasibility study

Introduction

Chronic conditions present a significant risk to the world population and cause substantial financial and health related burdens resulting in low quality of life of those affected [1]. Affecting more than half of the population in the US in 2016, chronic diseases are already a leading cause of death and their prevalence is expected to rise even further. [1]. In addition to ongoing treatment and medical oversight, disease management is a key pillar for chronic condition alleviation by aiming to minimize their symptoms, resulting functional impairments, and related exacerbating risks [2].

Successful disease management often requires a trustful collaboration between healthcare professionals, patients, and their family [3]. In addition, patients require specialized cognitive and behavioral skills to deal with their condition [4,5]. This is especially important for affected children who have to deal with their disease for their upcoming future [3,6].

An emerging tool for the management of chronic disease is the use of digital health interventions, as they can educate and engage patients through a direct channel that supports communication with physicians and healthcare professionals [7,8] and enables the scale-up of personalized and behavioral interventions at low cost disorders [1,9]. They bring medical care outside the clinical setting to provide ongoing support and communication in everyday monitoring and management [1]. Indeed, several recent studies have provided some evidence supporting the patient benefits of such digital interventions, particularly in children and adolescents [10–14]. In addition, conversational agents (CAs), i.e. computer programs that imitate interaction with human beings, show promising results with respect to patient satisfaction [15], therapeutic alliance [16,17], and treatment success [18]. Digital health interventions in the form of mobile applications can be particularly effective for children as they provide an attractive channel for education and management through the possible integration of multimedia content such as audio or video [19]. CAs as part of such interventions can act as mediating social actors, i.e. they take over not only a significant amount of the intervention delivery in a scalable way but also coordinate the communication between healthcare professionals, family members, and patients if required.

The present study focuses on asthma. Affecting approximately 235 million patients, asthma is one of the most common chronic diseases worldwide [20]. Asthma is characterized by reversible airway obstruction [21]. Its symptoms include wheezing, shortness of breath, and coughing [22]. Asthma is associated with high financial and health costs, with total annual asthma costs in the US estimated at 56 billion USD in 2011 [23]. Depending on the country, the mean cost of asthma care per patient per year can range from 1900 USD in Europe to 3100 USD in the United States [23]. Even though lack of medical treatment leads to significantly reduced quality of life, the management of asthma still presents a daunting challenge because the exact cause of asthma is not well-known and its appearance varies significantly between individuals [24].

For asthma, specific cognitive skills required for disease management include knowledge about asthma triggers and the importance of medication inhalation adherence as well as behavioral skills in the form of e.g., the application of correct inhalation techniques. Further, asthma education and health literacy are fundamental to self-management since better understanding of their condition would help patients avoid the negative effects of poor asthma control [25–27]. Studies have shown that low levels of health literacy have been linked with adverse health outcomes like more frequent hospitalization and longer stays, even after controlling for severity of illness and socioeconomic variables [28,29].

However, young patients still face problems related to both cognitive and behavioral skills that hinder their ability to effectively administer asthma medications [30–35]. For example, knowledge about asthma or important facets of asthma control such as importance of medication adherence might change over time, making it necessary for patients to continuously update their knowledge base [36–40]. Another common concern is poor technique during medication inhalation, leading to reduced dispersion of the drug in the lungs and subsequent decreased asthma stability and lowered clinical effectiveness of the delivered drug [41–44].

Numerous mobile applications have been developed for the management of asthma with particular focus on tracking symptoms or medications [45]. Asthma apps targeted at children often include a gamification component to increase engagement and familiarize them with aspects of asthma monitoring and management like medication intake [46,47]. However, and in addition to shortcomings of asthma management related to cognitive and behavioral skills, children often face problems with such technological solutions when they are not integrated into existing healthcare systems and do not allow for explicit support by healthcare professionals or family members. Without a dedicated party or mediator, it often becomes a challenge to integrate all these relevant stakeholders, i.e. healthcare professionals, family members, and the patients themselves, into the disease management process.

Additionally, due to absent or insufficient motivation strategies such as interactivity, proper incentives and rewards [48], and experiential value [49–51], the effects of the previously reported digital interventions in asthma, such as the health condition of the young patients, are prone to be negatively affected by the temporal decline in the patients' engagement and motivation [10,52–54]. The patient's motivation to comply with digital interventions and adhere to therapeutic tasks may be further diminished by various factors such as family routines, child-raising issues, social issues [55], and trust, communication and empathy with healthcare professionals [56]. Moreover, there is evidence that shared decision making and collaboration between patients, parents, and healthcare professionals are key success factors in guided asthma self-management programs with improved adherence and health outcomes

[55].

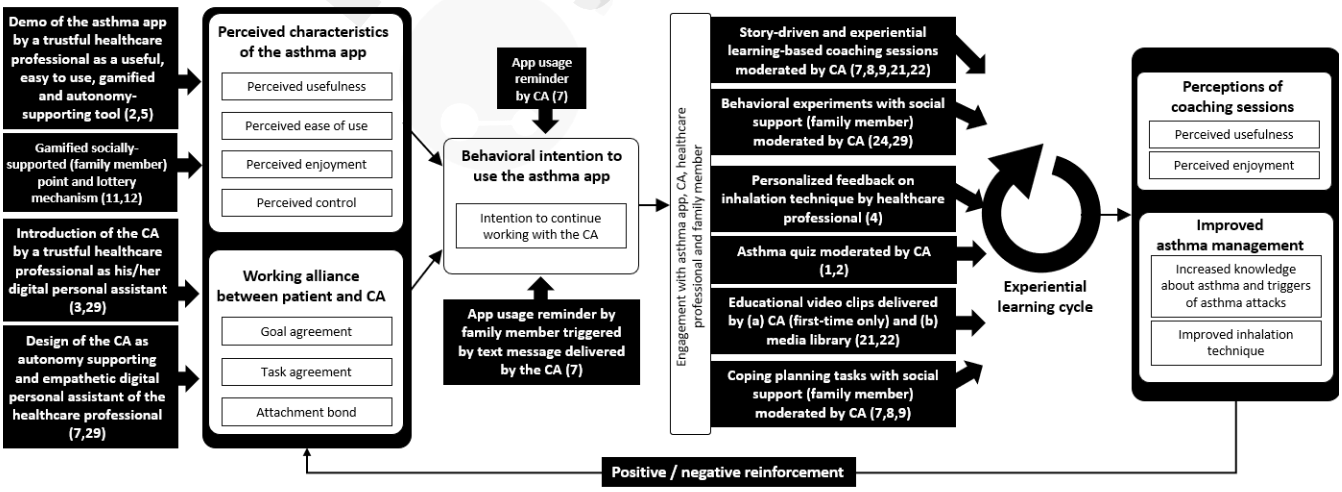
Against this background, our research questions are (1) whether CAs would be in general adopted for developing a trustful collaboration between healthcare professionals, young patients, and their family, and (2) whether they could have a positive impact on the management of asthma in children. To answer these questions, the current work has three objectives: (1) To describe the design of MAX, a CA-delivered asthma intervention that supports healthcare professionals targeting children-parent teams in their everyday lives; (2) To assess the (a) reach of MAX, (b) CA-patient working alliance, (c) acceptance of MAX, (d) intervention completion rate, (e) cognitive and behavioral outcomes, and (f) human effort and responsiveness of healthcare professionals in both primary and secondary care settings.

Methods

Conceptual model

Following the preparation phase of the multiphase optimization strategy for behavioral interventions [57], we started with the design of the conceptual model of MAX (see (Figure 1)). The design of the conceptual model was theoretically informed by related work covering asthma management in children (see Introduction), information systems and technology acceptance research [49–51,58], working alliance [59,60] linked to CAs [16,61–64], behavior change techniques (BCTs) [65], and experiential learning theory [66]. Moreover, feedback from four asthma experts of the Swiss Lung Association, two pediatric pneumologists of Swiss children's hospitals, young asthma patients and their parents, and lessons learnt from prior work, in which we developed a CA for children with obesity [67,68], was used in the design process. The resulting conceptual model reflects the causal chain triggered by intervention components that target (1) the engagement of the young patients with the asthma app, the CA, the healthcare professional and supporting family member (left part of (Figure 1)) and (2) the outcomes of the intervention (right part of (Figure 1)).

Figure 1. Conceptual model of the intervention. Note: CA = conversational agent; Intervention components are represented by black boxes; behavioral change technique numbers [65] are listed in brackets for each intervention component



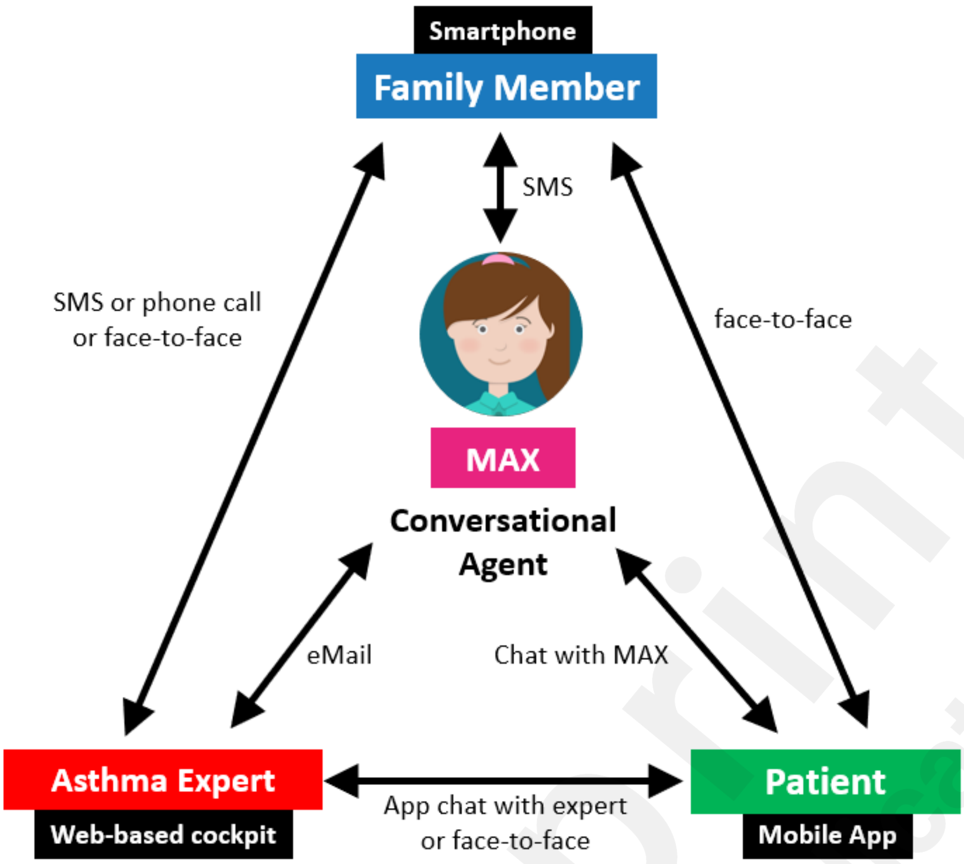
Communication concept

The communication concept of the intervention allowed patients to engage with the asthma app, the CA MAX, healthcare professionals, and family members via different communication channels. The communication concept is depicted in (Figure 2). In line with self-determination theory [69], which describes autonomy, i.e. the need to self-regulate one's experiences and actions as important predictor of engagement [70], the setup of this communication system allowed patients to independently decide with whom to interact and when, to establish relatedness to all involved stakeholders, and to ultimately increase their competence in the form of improved asthma management.

The CA itself followed a pre-defined intervention schedule route (see (Multimedia Appendix 1 and 2)) to communicate with all participating groups, i.e., with healthcare professionals via email, with patients via a mobile chat app and with a family member via Short Message Service (SMS) (see (Figure 2)). On top of these channels, there was an on-demand option to communicate via these and the other channels (e.g., phone call or face-to-face interaction when required or triggered by parents, the patient, or the healthcare professional).

Besides the mobile app, the intervention offered a web-based cockpit (see (Multimedia Appendix 3), which was only accessible to the participating healthcare professionals to interact with their patients when required for a coaching session, for monitoring their performance, or accessing their personal information such as patient ID. Patients first accessed the MAX app via an QR code printed on a physical card, which was handed out to them by their healthcare professional at the beginning of the intervention (see (Multimedia Appendix 4)). Each participant was linked to a personalized code printed on this card. This connection between patient and healthcare professional allowed the CA to know the treating health professional so that it can link back to its assigned human in case needed.

Figure 2. Communication concept of social actors, i.e. MAX combines different communication channels and incorporates family members, patients, and asthma experts into on-site and remote counselling sessions.



Intervention components triggering adoption of and adherence to MAX

To trigger engagement and in line with the theory of planned behavior [71], self-determination theory [69], and technology acceptance research [49,50,58], perceived characteristics of the asthma app (i.e. perceived usefulness, ease of use, enjoyment and control) and working alliance with the CA (i.e. goal agreement, task agreement, and attachment bond) were hypothesized to positively influence the behavioral intention to continue working with the CA.

To positively influence the perceived characteristics of the asthma app, healthcare professionals, who aim to build a trustful relationship with their patients as this is central in healthcare situations [72,73], were asked to *demonstrate the app to their patients as a useful, easy to use, gamified and autonomy supporting tool* for their asthma management. They hereby provided information on the consequences of behavior to the individual (BCT 2, [65]) and aimed at goal setting (BCT 5, [65]) early on. They introduced patients to the overall communication concept of MAX (see (Figure 2)), which allowed the integration of all involved stakeholders and the realization of a hybrid ubiquitous coaching approach via on-site and remote counselling sessions. It further aimed at attaining the perception of the CA as a trustworthy social actor that complements the healthcare professional and family team.

Moreover, a *gamified and socially supported point and lottery mechanism* was implemented as an intervention component to positively influence the patient's perceived enjoyment of the app, which was designed to influence the subsequent behavioral intention of patients to use the asthma app. This intervention component was informed by BCTs 11 and 12 (i.e., Prompt review of outcome goals and Prompt rewards contingent on effort or progress towards behavior, [65]). In detail, patients received 10 points for each finished coaching session and could achieve 160 points in total, covering the 14 intervention coaching sessions as well as the onboarding session and a pre-test health literacy quiz. An additional 10 points were rewarded for active participation of a family member according to the session requirements (e.g., recording a video of the inhaling patient to examine the inhalation technique). Here, 70 additional points could be earned. Upon finishing the complete intervention program within 30 days, the total number of points accumulated until then were doubled and patients received automatic reminders about how many days they had left for qualifying to double their points during the program. Also, an extra 100 points were awarded when the family member completed a final survey at the end of the intervention and handed out a hereby created unique code to the young patient to withdraw the bonus points. The final total amount of achieved points were converted into chances for a lottery, whereas more points translated into more chances. Three winners were drawn from each participating Swiss canton (for more details on the study design see section *Study design*). Each winner received a gift voucher worth 50 USD for Apple's App store, Google's Play store or a visit to local movie theatre.

To build up a working alliance, healthcare professionals were asked to *introduce the CA as their personal digital assistant* (BCT 3 and 29, Provide information about others' approval and Plan social support/social change, [65]). In addition, we also designed the *CA as an autonomy supporting* (e.g., patients were able to control and setup a date and time of the digital coaching sessions) *and empathetic digital assistant of the healthcare professional* (e.g., the CA introduced itself as the personal assistant of a healthcare professional by mentioning his/her name, and, several times during the intervention, the CA asked the patients about their emotional state and provided personalized feedback based on their answers) in accordance with BCTs 7 and 29 (Action planning and Plan social support/social change, [65]).

Moreover, *app usage reminders* were triggered by the CA as in-app notifications (after 1h, 1 day and 3 days of no interaction) and through a separate communication channel, i.e. via SMS (after 5 days to the patient and after 7 to the family member's smartphone), to positively influence the intention of the patient to continue working with the CA. These reminders endorsed action planning (BCT 7, [65]) and further supported the development of relatedness [69] between patients and their parents as important participants of the intervention.

Intervention components triggering experiential learning and outcomes

Four distinct intervention components as depicted in (Figure 1) enabled an experiential learning cycle [66] and were assumed to influence the outcomes of the intervention, i.e., perception of the coaching sessions (i.e., perceived usefulness and perceived enjoyment) and the improvement of individual asthma management (i.e., increased knowledge about asthma and triggers of asthma attacks, and improved inhalation technique). Experiential learning describes learning as a process that is continously grounded in experience and understood as holistic process that fosters adaptions of the learner to the surrounding reality [66]. The four cyclic steps that describe this process – active experimentation, concrete experience, reflective observation, and abstract conceptualization [66] – are triggered by the intervention components.

The *story-driven and experiential learning-based coaching sessions moderated by the CA* as overarching intervention component fosters active experimentation [66], concrete experiences [66], and implements several BCTs (7-9,21,22, see [65] for detailed description and (Multimedia Appendix 1 and 2) for an overview of the coaching sessions). For patients, coaching sessions were moderated by the CA MAX, which offered a relatively simple chat-based interface with pre-defined answer-options to multiple-choice questions, free text input (e.g., asking for the participant's nickname), or number input fields (e.g., asking about the participant's age), and a linguistic style that evoke interpersonal closeness as this is assumed to be positively related to the attachment bond between patient and CA [59,74]. MAX mimicked the behavior of a real human being chatting by using emojis and some humor to build up a social relationship [75] and working alliance [61] when conversing with patients (see (Multimedia Appendix 7) and (Multimedia Appendix 8). To address participants' accountability, MAX referred to earlier tasks and activities and gave positive reinforcement. The CA could also send out personalized messages every other day to initiate a conversation, where it began the dialogue with a warm greeting, followed by questions about the participants' mood, such as "How are you today?".

In total, the intervention consisted of 14 individual coaching sessions, whereas the topics of the coaching sessions were designed to increase cognitive skills (i.e. knowledge about asthma) and behavioral skills (i.e. inhalation technique). Patients could conduct a maximum of one coaching session per day in order to reduce smartphone addiction [76], where each coaching session was designed to last between 10 to 15 minutes. Several coaching sessions required the aid of the supporting family member, for example, to film the patient performing an inhalation (for an exemplary video clip, see (Multimedia Appendix 9). The family member was invited by the MAX CA via a corresponding SMS at the time the patient made the appointment for that specific coaching session. A detailed schedule of the intervention with an overview of the coaching sessions is outlined in (Multimedia Appendix 1).

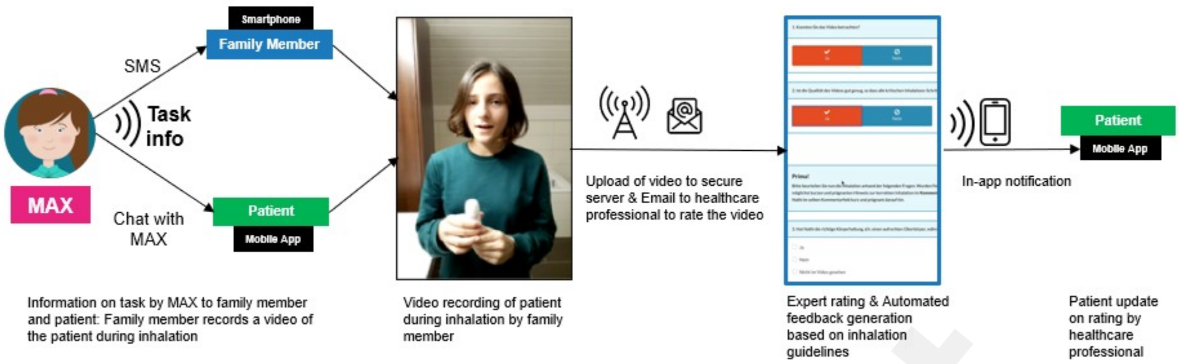
Assuming that the need to self-regulate one's experiences and actions as important predictor of engagement [70] as posited by self-determination theory is also true for digital interventions, the intervention schedule was flexible, which is an innovative approach compared to other interventions [17,77–80] and allowed accommodating to the patients' needs like school stress or sickness. Patients could individualize their intervention schedule since they had the possibility to postpone exercises at their own discretion. This gave patients significant control over the interaction progress and its overall duration. In theory, they could prolong their intervention significantly, but above described point reward system incentivized the completion of the program within 30 days by doubling all achieved points when patients complied to this time frame.

The curriculum and storytelling aspects of the intervention were derived from a validated Swiss health literacy comic for children with asthma published by the Swiss Lung Association [81]. Based on this comic, one expert in digital media, didactics, and learning theories wrote a digital health literacy storybook (see (Multimedia Appendix 10 and 11) including scripts for 11 health literacy video clips for children with asthma. The storybook was proofread and validated by two asthma experts from the Swiss Lung Association and two paediatric pneumologists. Additionally, already established video clips covering correct inhalation techniques for children with asthma were integrated into intervention coaching sessions. These video clips had been produced under the direction of Swiss healthcare professionals and are currently used by a number of Swiss hospitals and patient organizations in their health literacy programs (for links to the video clips see (Multimedia Appendix 1 and 2)).

Concrete learning experiences [66] were enabled through the intervention component of *behavioral experiments with social support (family member) moderated by CA*. This design allowed patients to relate to the CA and to their social support person. The behavioral experiments addressed asthma management and aimed at improving patients' competence with asthma management [69]. In addition, they enabled environmental restructuring (BCT 24, [65]) and planning of social support/social change (BCT 29, [65]).

During onboarding, healthcare professionals checked inclusion criteria with the help of a study recruitment assessment sheet (see (Multimedia Appendix 5 and 6) when patients were interested in participating. When patients decided not to participate in the study, healthcare professionals noted down the corresponding reasons. Further, patients chose their supporting family member and provided their own and their parent's mobile phone numbers to enable communication via the asthma app and mobile phone. Family members provided support to young patients as intervention component by. For example, they were asked to record a short video clip during inhalation as part of a coaching session or fill out a final intervention survey that enabled the young patients to gain more points for the above described lottery. (Figure 3) depicts an exemplary workflow of the integration of the different stakeholders into the MAX intervention in the course of a behavioural intervention with social support. See (Multimedia Appendix 9) for an exemplary video clip. The family member and the patient are notified over their respective communication channels (i.e., SMS and in-app) about an upcoming task. Upon completing the task (here: recording the patient during inhalation to evaluate any inhalation mistakes), the CA MAX uploads the video on a secure server and triggers an email notification to the child's healthcare professional to review the video. Then, the healthcare professional assesses the inhalation according to pre-defined inhalation guidelines (e.g., was there a correctly executed exhalation before drug inhalation?) with the tags "correct", "not-correct" or "not visible in the video". According to these assessments, an automated feedback message is generated, which could be personalized by the healthcare professional. In a last step, the healthcare professional sends the personalized feedback message via the web-based cockpit and the patient receives it as an in-app notification in a separate "healthcare professional" chat channel. Depending on the severity of the inhalation mistakes, indicated by the healthcare professional with an additional yes/no tag, the MAX CA would ask the patient and supporting family member to redo the video recording of the inhalation technique at the beginning of the next coaching session.

Figure 3. The MAX intervention integrates patients, family members, and healthcare professionals and allows a ubiquitous experiential learning experience. Here, session 1 is shown, in which patients were prompted by the MAX CA to record a video of them during inhalation with the help of their support family member, who were additionally informed about the task via SMS. Once patients had created and uploaded the video to a secure server, healthcare professionals received an email to assess the video clip with regards to inhalation mistakes. Patients received their final feedback with comments via in-app notification. For an exemplary video clip see (Multimedia Appendix 9).



The intervention components *personalized feedback on inhalation technique by healthcare professional, asthma quiz moderated by CA*, and *educational video clips delivered by (a) CA (first-time only) and (b) media library* allowed for reflective observation [66]. In particular, healthcare professionals assessed the inhalation technique based on video clips record by a patients' family member, provided individual feedback to the patients, and provided normative information about others' behavior (BCT 4, [65]). This was done via a dedicated chat-channel in the web-based MAX cockpit for healthcare professionals and the mobile MAX application (see (Figure 3)) and during on-site visits. This interaction setup extended the dyadic interaction between patient and CA resulting in a ubiquitous experiential learning experience besides fostering the relatedness between patients and healthcare professionals as relevant interaction partners [69].

Healthcare quizzes were an integral part of the intervention. Patients took a healthcare quiz at the beginning and end of the intervention as well as short quizzes that were integrated into the conversational turns with the CA MAX. These elements of gamification aimed to increase cognitive skills and provided information on consequences of behavior both in general as well as to the individual (BCT 1 and 2, [65]). Participants could choose between multiple answers and received feedback depending on the accuracy of their chosen answer. In line with self-determination theory, the quizzes and educational video clips, which were informed by BCT 21 and 22 (Provide instruction on how to perform the behavior and Model/Demonstrate the behavior, [65]) aimed at strengthening the individual competence of the young patients for managing their health condition [69].

The intervention component *coping planning tasks with social support (family member) moderated by CA* closed the experiential learning cycle. It allowed patients to engage in abstract conceptualization [66] of the behavioral and cognitive skills that they had learned before. Also, this intervention component supported the improvement of asthma management as the intervention outcome. In line with self-determination theory [69], it further allowed patients to acquire overall increased competence via the integration of BCTs 7-9 (Action planning, Barrier identification/problem solving, and Set graded tasks, [65]).

Finally, we assume that there is a positive / negative reinforcement link that connects the outcomes of the conceptual model with the perceived characteristics of the app and working alliance with the CA. This encourages patients to continue working with the CA and increases engagement behavior, especially for young patients. That is, if neither the coaching sessions are perceived useful and joyful nor improvements of asthma management can be observed as a result of actual participation in the intervention the expectations, then engagement in the intervention will likely decrease, which has been shown in related interventions [82,83].

Technical implementation

The intervention was developed with the open-source software platform MobileCoach (www.mobile-coach.eu) [68,84], which has been already used successfully for various clinical and public health interventions [17,67,77,79,80,85,86] and ecological momentary assessments [87–89]. MobileCoach is available under the academia- and industry-friendly open-source Apache 2.0 license. MobileCoach-based interventions are delivered via the short-message service (SMS), email messages, and mobile applications for the Android and iOS operating systems. Moreover, MobileCoach-based interventions use a CA for intervention delivery. MobileCoach client applications for iOS and Android use in-app encryption of user data. This included password protected access to the MobileCoach Designer, a web-based interface for intervention authors, and a web-based cockpit for chat interactions with human health coaches. Additionally, Secure Sockets Layer (SSL) encoding was implemented to ensure privacy and safety of any data transfer between the mobile apps, the web-based cockpit, MobileCoach Designer, and the MobileCoach server.

Costs of intervention components

Assessing the costs of each intervention component is relevant for real-life implementations [57]. Therefore, economic factors (e.g., budgets of hospitals or healthcare professionals' time allocations) also need to be taken into consideration. The development costs of the MAX intervention, which is currently not classified as software as medical device in Switzerland and which is still a prototype and not a product, sums up to circa 250.000 USD. This includes costs for the storybook, software development, project management, artwork, and production of video clips and the personalized QR code cards. Moreover, other costs per participant are linked to intervention components that involve either incentives (see above) or efforts by healthcare professionals. Regarding the latter, there are three such intervention components in the MAX intervention. First, healthcare professionals carry out the onboarding of patients, which encompasses two intervention components (i.e. (1) *Demo of the asthma app by a trustful healthcare professional as a useful, easy to use, gamified and autonomy-supporting tool* and (2) *Introduction of the CA by a trustful healthcare professional as his/her digital personal assistant* (see (Figure 1)). Associated costs with these two intervention components are time needed for preparation, conduction, and potential post-processing of this task. Second, providers were involved at the assessment of short video clips send by the participants as described by the intervention component *Personalized feedback on inhalation technique by healthcare professional* (see (Figure 3) for detailed explanation and illustration of this task and the according process). Here, associated costs concerned the time needed to assess the video clip and compile their feedback. This process was costly due to the economic costs of healthcare professionals but could be reduced to a certain extent by automatically providing a video tutorial showing how to perform the inhalation assessment with the web-based MAX cockpit. Since the video tutorial was integrated into every email that triggered an assessment, access to the tutorial was straightforward and thus low-cost. All other intervention components have low running costs as they are scalable due to their digital setup (e.g., interaction over mobile app and with CA, digital lottery, coaching sessions moderated by CA, etc.).

Evaluation of the Intervention

Study design

MAX was assessed in a single-arm feasibility study in two home care settings offered by the Swiss Lung Association and four secondary care settings at hospitals in the German-speaking part of Switzerland. The study was approved by the institutional review board of ETH Zurich (reference number: EK 2018-N-59).

Sample size considerations

The primary objective of this single-arm feasibility study was to develop, implement, and test the MAX intervention. Therefore, the study was exploratory by nature and thus did not include a detailed power analysis to determine a particular sample size. However, to identify a relevant amount of usability problems, at least 20 participants were required according to heuristics in usability engineering [90]. Moreover, to assess the potential reach of the intervention we decided to approach between 90 and 100 participants.

Inclusion criteria

The following inclusion criteria were defined and outlined in the corresponding intervention flyer (see (Multimedia Appendix 12 and 13))*:*

(1) 10- to 15-year-old German-speaking patients diagnosed with asthma who have access to a smartphone with Google's Android (Version 4.1 or higher) or Apple's iOS (9.3 or higher) operating system and Internet access via a data contract (3G/LTE) or wireless LAN (WIFI) to watch the health literacy video clips, to interact with the CA, and to fill out the online surveys.

(2) Availability of a German-speaking family member of the patient (usually mother, father, or older sibling) who has access to a smartphone with Internet access via a data contract (3G/LTE) or wireless LAN (WIFI) to be able to e.g. to receive the SMS from MAX and to fill out the online survey at the end of the intervention. This supporting family member must be motivated to support the young patient every second intervention day.

There were no exclusion criteria.

Recruitment and management of study participants

The participants were recruited during a three-month period from January to March April 2019 via participating healthcare professionals at six study sites in Switzerland. The study sites were two home care settings offered by the Swiss Lung Association (one in the canton Bern and one in the canton Thurgau) and four secondary care settings at hospitals in the German-speaking part of Switzerland. The healthcare professionals received instructions on how to install and use the mobile app before the start of the intervention. Additionally, healthcare professionals were provided with study instructions so they could consistently recruit and manage their patients during the study (see (Multimedia Appendix 14 and 20)). This document (and every triggered email when a inhalation video clip was submitted) also included a link to a video tutorial (https://vimeo.com/301853805/55ffddc87b) that shows how to perform the inhalation assessment with the web-based MAX cockpit. They were also trained to introduce the MAX CA as their personal digital assistant. The healthcare professionals recruited patients with a flyer that was personalized for each healthcare expert during their consultation hour (see (Multimedia Appendix 12 and 13) for an example of a personalized flyer), or via by email, by post, or via telephone. Additionally, participants could access a website (https://www.max-asthmacoach.ch/) for more information on the intervention (e.g. with a demonstration video clip showing chatting with the MAX CA), study participation, and frequently asked questions. If a candidate was interested in participating, inclusion criteria were checked by the healthcare professional, or, if the patient was not interested, corresponding reasons were noted down to better understand patient's decisions (see (Multimedia Appendix 5 and 6). After reading a more detailed study information (see (Multimedia Appendix 15 for the German version) and signing the consent form (see (Multimedia Appendix 16) for the German version), the healthcare professionals gave the patients his/her personal MAX intervention card in the form of a business card with a QR code (see (Multimedia Appendix 4)). The QR-Code could be used with the standard photo app of a smartphone (capable of reading QR codes) and automatically forwarded the patient to either the Android or Apple store, depending on the type of their smartphone, to download the mobile app.

Measures

For assessing the various aspects of the intervention, we used basic demographic, asthma- and intervention-related information (i.e. age, gender, years since asthma diagnosis, the supporting family member during the intervention (e.g. mother), usage of mobile operating system, and perceived uncertainty with asthma management (CA saying: "I have been taught some things about asthma by my development team, but I am still unsure from time to time. I'm sure you feel the same?" answer options are "No, I am an asthma expert" (1), "I know quite well how to manage my asthma" (2), "Every now and then I feel insecure too." (3), "Yes, I have been uncertain a lot before." (4))). In addition, the following metrics and instruments were assessed.

The *reach* of the intervention was measured by the ratio of approached participants to those who started to interact with the CA MAX on the mobile app. Reasons for non-participation were also gathered.

Working alliance between the patient and the CA MAX was assessed with a German-adapted version of the Session Alliance Inventory [91] after coaching sessions 2, 8, and 14 (e.g., "MAX and I respect each other" with answers anchored on a 7-point Likert scale ranging from "never" (1) to "always" (7) (see (Multimedia Appendix 17)).

Acceptance of the intervention was assessed in several ways. First, perceived usefulness ("The app helped me to increase my knowledge about my asthma"), ease of use ("The app was easy to use"), enjoyment ("I found the app enjoyable."), control ("I could control many aspects of the app") and usage intention ("How much would you like to continue working with Max?") were assessed by patients at the end of the intervention with instruments adapted from information systems research [50,92]. Single-item measures were used to reduce the burden of the intervention and answers were anchored on 7-point Likert scales ranging from "strongly disagree" (1) to "strongly agree" (7). Second, to get a more granular assessment for each coaching session, perceived usefulness ("Did you learn something new?" with answer options "No, I knew everything" (1), "Yes, some new aspects" (2), and "Yes, a lot of new aspects" (3)) and perceived enjoyment ("Did you enjoy today's lesson?" with answer options anchored on a 5-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5)) were assessed at the end of each of the 14 coaching sessions randomly. A random assessment procedure with a maximum chance of 50% was implemented, again, to reduce the burden of the intervention. If a participant had assessed the previous session, no assessment was triggered. Third, participation of the supporting family member ("Have you been supported today by the person you indicated?" with answer options "yes" and "no, unfortunately not") was measured at the end of each coaching session which asked for social family support, i.e. in sessions 1, 3, 5, 7, 8, 9, and 12. Fourth, during the setup procedure of the mobile app we measured which of the two gender-specific characters of the MAX CA (either the female *Maxime* or male *Maximilian*) was selected. Fifth, based on app usage data, we measured when participants drop out of the intervention, i.e. did not use it anymore for 60 days. Sixth, we assessed the number of conversational turns between patients, healthcare professionals, and the CA MAX. Finally, we also collected positive aspects of the intervention ("What did you really like about the intervention?") and suggestions for improvement ("What needs to be definitely changed in a future version?") from patients (via an in-app conversation with the MAX CA), the supporting family member (via a web-based survey for which the MAX CA sent a link via SMS to the family member) and healthcare professionals (via a personal interview conducted by co-author SH). All interview items are available in (see (Multimedia Appendix 17).

Knowledge about asthma (i.e. *cognitive skill*) was assessed at the beginning of the intervention (i.e. at the end of the introductory chat with the CA MAX) and in the last session by a validated health literacy quiz for children with asthma with a quiz score ranging from 0 (no knowledge) to 11 (good knowledge) [81,93] (see (Multimedia Appendix 18)).

The inhalation technique of each patient (i.e. *behavioral skill*) was systematically assessed by the patient's responsible healthcare professional with the help of pre-defined evaluation criteria (see (Table 3)). These criteria were developed by healthcare professionals of the Swiss Lung Association and the participating pediatric pneumologists (for details see (Multimedia Appendix 17)). The number of mistakes were counted and it was decided for each assessment and healthcare professional whether there was a serious, potentially life-threatening, inhalation mistake.

Intervention completion rate was assessed by dividing the number of participants who finished the intervention within 60 days by the number of participants who started to interact with the CA MAX.

Finally, we measured *human effort and responsiveness of healthcare professionals* to better understand the costs per patient related to the intervention. Here, these costs refer to (1) the onboarding time per patient including a demo of the app and an introduction of the CA MAX including the time needed for preparation, conduction, and potential post-processing of this task, (2) the assessment of video clips with the time needed to assess the video clip and compile their feedback, and (3) the number of conversational turns in the manual / human-managed chat channel of the MAX app. For the first cost aspect, we asked the healthcare professionals after the intervention to estimate the average onboarding time. For the second cost aspect, we objectively measured the duration required to review the video clips by healthcare professionals, the technical quality of the video clips (e.g. "Did *[patient]* exhale enough before inhalation?"). For the third cost aspect, we counted and compared the number of conversational turns between the patient and (a) the MAX CA and (b) the healthcare professionals to better understand the extent to which the intervention can be delivered in a scalable way. In addition, we measured the number of SMS reminders sent to patients and the supporting family member, since these also trigger costs.

Finally, we measured the time until patients received their feedback, i.e. from the moment the video clip was submitted via the mobile app until the feedback was provided as further aspect of *human effort and responsiveness of healthcare professionals*.

Results

The descriptive statistics of the study are shown in (Table 1). Out of the 49 participants who started interacting with MAX, 33 were male with an average of 12 years and 5.5 years since asthma diagnosis. Only 13 of the participants indicated that they were uncertain a lot (N=2) or every now and then (N=11) with managing their asthma. The majority (63.3%) chose their mother as supporting family member and iOS was used slightly more often than the Android operating system.

The flow chart of the MAX intervention including details for non-participation and dropouts is shown in (Figure 4). Reach was 49.5% with 49 out of 99 approached patients downloading the app and starting to interact with the MAX CA. Availability of a smartphone was the major reason for non-participation (N=14, 14%), and the most frequent dropouts happened during the onboarding (N=3) and Coaching Session 6 (N=3). To better understand sessions after which participants no longer interacted with the MAX CA (i.e. they dropped out), (Figure 5) indicates the key task involved in each “drop out session”. It can be thought that the effort to complete a specific coaching session and disclosing personal information (e.g. recording the inhalation technique with the face of the patient) may have led to a dropout. Participants who finished the intervention (N=37) did so on average within three weeks which was within the incentivized duration of four weeks.

Figure 4. Subject acquisition and participation flow chart.

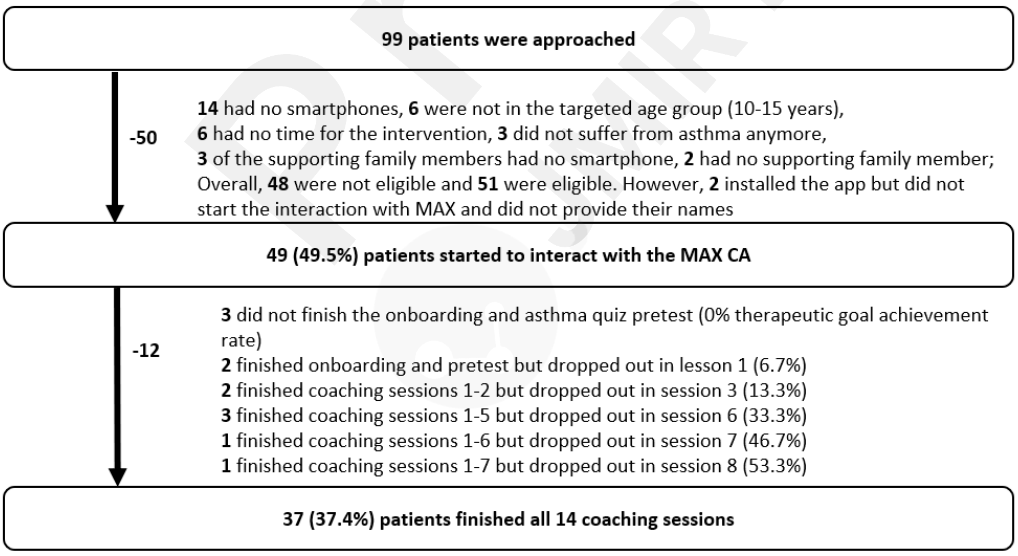
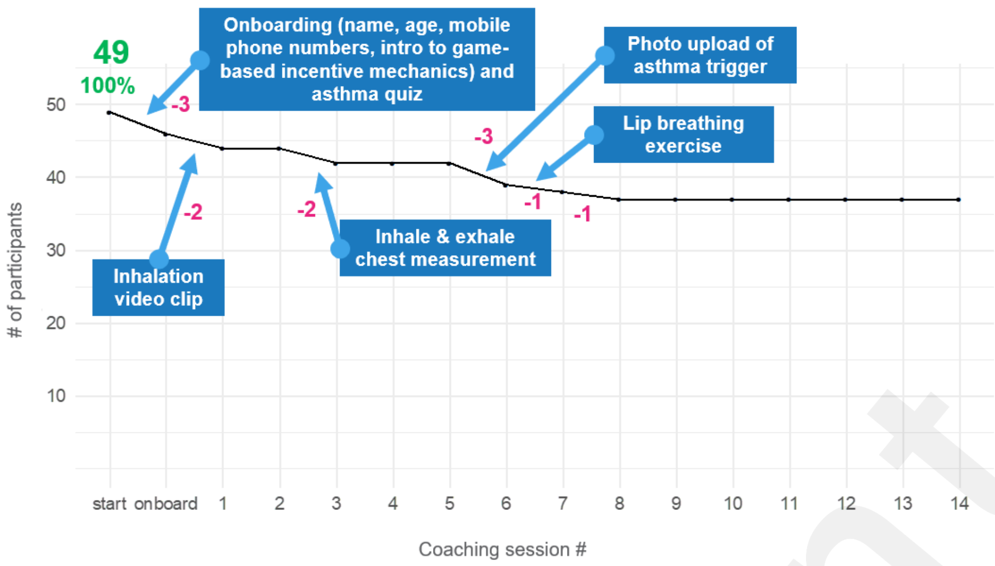


Figure 5. Participants for each coaching session and potential reasons for dropouts.



The *session alliance inventory* indicated high working alliance ratings between the young patients and the MAX CA from the very beginning of the intervention until the end (Table 1).

Technology acceptance perceptions of the young patients regarding the mobile app are shown in (Table 1). All mean values lie clearly above the neutral scale value of four indicating positive evaluations of the mobile app. Moreover, patients learned new aspects about asthma management and enjoyed the coaching sessions. Out of 275 coaching sessions, in which a family member was asked to support the young patients, patients indicated 269 times (97.8%) that they were supported by a family member. For the gender-specific choices of the MAX CA, all male/female participants chose the male/female CA character.

Table 1. Descriptive statistics of the patient-derived quantitative measures. Note: the % in brackets indicate the percentage out of the 49 app installations

Construct	**N (%)**	**Mean (SD)**
Demographic and asthma related data		
Females	16 (32.65%)	n/a
Males	33 (67.35%)	n/a
Age	49 (100%)	12.04 (1.54)
Years since asthma diagnosis	39 (79.59%)	5.61 (4.17)
Perceived uncertainty with asthma (measured in Coaching Session 4)	44 (89.80%)	2.05 (0.81)
Mobile operating systems		

Android	22 (44.90%)	n/a
iOS	27 (55.10%)	n/a
Supporting family member		
Mother	31 (63.27%)	n/a
Father	9 (18.37%)	n/a
Older brother	2 (4.08%)	n/a
Older sister	3 (6.12%)	n/a
Other	3 (6.12%)	n/a
Patient-MAX CA working alliance		
Coaching Session 2	44 (89.80%)	6.34 (0.73)
Coaching Session 8	39 (79.59%)	6.14 (0.96)
Coaching Session 14	36 (73.47%)	6.34 (0.87)
Technology acceptance of mobile app		
Perceived Usefulness	36 (73.47%)	6.42 (1.09)
Perceived Ease of Use	36 (73.47%)	6.75 (0.65)
Perceived Enjoyment	36 (73.47%)	6.47 (1.06)
Perceived Control	36 (73.47%)	5.53 (1.78)
Intention to continue working with the MAX CA	36 (73.47%)	5.58 (1.73)
Perceived usefulness of coaching session		
Coaching Session 1	22 (44.90%)	1.91 (0.68)
Coaching Session 2	10 (20.41%)	2.50 (0.53)
Coaching Session 3	12 (24.49%)	2.58 (0.67)
Coaching Session 4	14 (28.57%)	2.36 (0.74)
Coaching Session 5	13 (26.53%)	2.54 (0.78)
Coaching Session 6	14 (28.57%)	2.29 (0.73)
Coaching Session 7	13 (26.53%)	2.38 (0.77)
Coaching Session 8	13 (26.53%)	2.31 (0.77)
Coaching Session 9	12 (24.49%)	2.58 (0.67)
Coaching Session 10	16 (32.65%)	2.50 (0.73)
Coaching Session 11	11 (22.45%)	1.82 (0.75)
Coaching Session 12	13 (26.53%)	2.38 (0.87)
Coaching Session 13	16 (32.65%)	1.88 (0.62)
Coaching Session 14	13 (26.53%)	2.15 (0.80)
Total	192 (100%)	2.28 (0.74)
Perceived Enjoyment of Coaching Session		
Coaching Session 1	22 (44.90%)	4.91 (0.29)
Coaching Session 2	10 (20.41%)	4.70 (0.48)
Coaching Session 3	12 (24.49%)	4.83 (0.39)
Coaching Session 4	12 (24.49%)	4.83 (0.39)
Coaching Session 5	13 (26.53%)	4.69 (1.11)
Coaching Session 6	14 (28.57%)	4.79 (0.58)
Coaching Session 7	13 (26.53%)	5.00 (0.00)
Coaching Session 8	13 (26.53%)	4.69 (0.48)

Coaching Session 9	12 (24.49%)	4.83 (0.39)
Coaching Session 10	16 (32.65%)	4.81 (0.54)
Coaching Session 11	11 (22.45%)	4.64 (0.92)
Coaching Session 12	13 (26.53%)	4.69 (0.85)
Coaching Session 13	16 (32.65%)	4.75 (0.58)
Coaching Session 14	13 (26.53%)	5.00 (0.00)
Total	190 (100%)	4.81 (0.56)
Duration to complete the intervention / one coaching session (based on data from participants finishing the intervention)		
Average duration in days	37 (75.51%)	21.46 (11.55)
Average days per coaching session	37 (75.51%)	1.43 (0.77)
Conversational turns between the patients and the MAX CA		
Participants finishing the intervention	37 (75.51%)	365.49 (11.85)
Participants not finishing the intervention	12 (24.48%)	129.58 (59.86)
Conversational turns between the patients and healthcare professionals		
Participants finishing the intervention	37 (75.51%)	1.68 (1.68)
Participants not finishing the intervention	12 (24.49%)	1.00 (1.35)
In-app (free of cost) and SMS reminders sent to patients and supporting family member		
Participants finishing the intervention	37 (75.51%)	11.57 (8.46)
Participants not finishing the intervention	12 (24.49%)	20.75 (15.88)
SMS reminders sent to patients after 5 days of non-activity		
Participants finishing the intervention	37 (75.51%)	0.24 (0.86)
Participants not finishing the intervention	12 (24.49%)	2.50 (1.68)
SMS reminders sent to supporting family member after 7 days of non-activity		
Participants finishing the intervention	37 (75.51%)	0.14 (0.67)
Participants not finishing the intervention	12 (24.49%)	2.00 (1.28)
Asthma knowledge (cognitive skills)		
Asthma quiz score onboarding (pre-test)	48 (97.96%)	7.73 (2.24)
Asthma quiz score coaching session 14 (post-test) (last observation carried forward, i.e. the pre-test value was used for 11 participants)	48 (97.96%)	8.79 (2.27)
Asthma Quiz Score Coaching Session 14 (post-test) (complete cases, no missing values)	37 (75.51%)	9.43 (1.76)

The detailed *qualitative feedback* with exemplary quotes is provided in (Multimedia Appendix 19) and summarized as follows. First, patients liked the educational content of the intervention and the text-based features of the CA the most. Second, supporting family members also highlighted the educational content besides the experiential value of the intervention. Third, healthcare professionals positively emphasized the perceived ease of use and the significant supporting role of family members in this intervention. For improvement suggestions to the intervention, patients indicated that there was too much predefined text. This concern was also shared by supporting family members. Healthcare professionals indicated that lack of access to smartphones, especially for young patients, was a limiting factor to further increase the reach of the intervention. In addition, healthcare professionals indicated the following features to be considered in a future version. First, they would prefer an adaptation of the inclusion criteria, especially regarding the age range in order to be able to further address younger and older patients.. Second, they suggested cooperating with pneumologists and GPs to expand the intervention to other health related topics or diseases (e.g. eating disorders or diseases with similar complexity as asthma). Third, they suggested integrating further interaction between the healthcare professionals and patients (e.g. follow-up questions).

Asthma knowledge (cognitive skills) scores at the beginning and end of the MAX intervention are shown in (Table 1). Paired sample t-tests revealed a significant increase in scores and large effects with two approaches, a complete case analysis ($N = 37$, $t = -3.68$, $df = 36$, $p < 0.001$, $d = 1.19$), and with the baseline observation carried forward ($N=48$, $t = -3.54$, $df = 47$, $p < 0.001$, $d=0.91$).

The *intervention completion rate* was 75.5%, i.e. 37 out the 49 patients finished the intervention.

Overall, 42 inhalation video clips were recorded and submitted to the healthcare professionals (Table 2). All of these clips had sufficient technical quality for evaluation. The majority of inhalant medications used were dry powder inhaler and metered-dose inhaler. The health professional's assessments of the *inhalation techniques* (behavioral skills) based on these video clips are listed in (Table 3). In summary, healthcare professionals identified 0.9 inhalation mistakes in each video clip (N=42). For two video clips, three serious inhalation mistakes were identified, eliciting a feedback to re-send a corrected video clip. After resubmission, no severe inhalation mistakes could be identified in the second video clip.

For the *human effort and responsiveness of healthcare professionals* (i.e. to better understand the per-patient costs related to the intervention), the average time of the app onboarding process (excluding study-specific discussions) was circa 15 minutes. Moreover, it took healthcare professionals an average duration of 221s to assess the videos clips with a clear difference between healthcare settings (average of 410s in primary care setting and 127s in secondary care setting, see (Table 2)). For the *responsiveness of healthcare professionals*, patients received feedback on their submitted video clips after an average of ca. 2.4 days (Table 2). In contrast to the assessment time, there were no differences between the healthcare professionals of the primary and secondary care settings. For the distribution of conversational turns, 99.5% (15,078 out of 15,152) took place between patients and the MAX CA, and only 0.5% (74 out of 15,152) occurred between patients and healthcare professionals (Table 1). This indicates a very low amount of human effort (i.e. between 1 and 1.7 conversational turns between a healthcare professional and patient, see Table 1). Finally, between 0.1 and 2.5 SMS reminders were sent out on average per patient by the MAX CA (Table 1), in addition to the seven SMS that were sent out to invite the supporting family members to join the seven "social support" coaching sessions.

The depersonalized data can be found on the Open Science Framework (https://osf.io/dpw9f/?view_only=3ddcfbc2007d4b36ae611f8b1dc9a5b5) for replication purposes and future analyses (the link will be replaced with a permanent link after acceptance of the manuscript). It should be noted that not all data can be published due to ethical considerations and to protect the privacy of the participants of this study.

Table 2. Descriptive statistics of inhalation video clip assessments (N=42)

Variable	**N (%)**	**Mean (SD)**
Inhalant		
Dry powder inhaler – Turbuhaler	17 (40.48%)	n/a
Metered-dose inhaler	16 (38.10%)	n/a
Dry powder inhaler – Diskus	9 (21.43%)	n/a
Duration of video clip assessments in seconds		
2 primary care providers	14 (33.34%)	409.51 (346.48)
4 secondary care providers	28 (66.67%)	126.94 (102.80)
Total	42 (100%)	221.13 (251.39)
Inhalation mistakes identified per submitted video clip		
2 primary care providers	14 (33.34%)	0.93 (0.83)
4 secondary care providers	28 (66.67%)	0.93 (1.30)
Total	42 (100%)	0.93 (1.16)
Days until feedback was provided (including weekends)		
2 primary care providers	14 (33.34%)	2.25 (1.83)
4 secondary care providers	28 (66.67%)	2.40 (1.81)
Total	42 (100%)	2.34 (1.80)

Table 3. Inhalation technique assessments by healthcare professionals. Note: _ indicates the name of the patient during the assessments

#	**Assessment question**	**N (%)**		
	Questions for all assessments (N=42)	**Yes**	**No**	**Not visible on the video**
1	Has _ the correct posture, i.e. an upright upper body, during inhalation?	42 (100%)	0 (0%)	0 (0%)
2	Did _ load / prepare the device correctly?	30 (71.43%)	4 (9.52%)	8 (19.05%)
3	Did _ exhale enough before inhalation?	30 (71.43%)	8 (19.05%)	4 (9.52%)
4	Did _ inhale deeply and long enough through the mouth during inhalation?	34 (80.95%)	7 (16.67%)	1 (2.38%)
5	Did _ hold his breath for 5-10 seconds? OR an alternative for the metered-dose inhaler: Were	38 (90.48%)	4 (9.52%)	0 (0%)

	10 calm breaths taken via the upstream chamber?			
6	Did _ exhale slowly afterwards?	33 (78.57%)	5 (11.90%)	4 (9.52%)
	Additional metered-dose inhaler questions (N=16)			
7	Has the cap of the dosing aerosol been removed?	13 (81.25%)	0 (0%)	3 (18.75%)
8	Was the metered dose aerosol shaken before inhalation?	10 (62.50%)	2 (12.50%)	4 (25.00%)
9	Was the upstream chamber used?	15 (93.75%)	1 (6.25%)	0 (0.0%)
10	Was the upstream chamber clean? (N=15, see 9)	14 (93.34%)	0 (0.0%)	1 (6.67%)
11	Was the age-appropriate upstream chamber used? (mouthpiece, mask) (N=15, see 9)	15 (100%)	0 (0.0%)	0 (0%)
12	Was there a whistling sound of the upstream chamber during inhalation? (inhaled too strongly and quickly) **reverse coded* (N=15, see 9)	11 (73.34%)	3 (20.00%)	1 (6.67%)
13	Did _ trigger the device at the right time during inhalation?	15 (100%)	0 (0%)	0 (0%)
	Additional dry powder inhaler question (N=26)			
14	Was exhaled incorrectly into the powder inhaler so that there is a risk of clumping? **reverse coded*	22 (84.62%)	3 (11.54%)	1 (3.85%)
	Additional question if the inhalant contained cortisol (N=32)			
15	Has _ rinsed his mouth with water after inhalation or eaten anything?	7 (21.88%)	2 (6.25%)	23 (71.88%)

Discussion

Primary findings

In this work we described the design of MAX, a smartphone-based and CA-delivered asthma intervention that supports healthcare professionals targeting children-parent dyads in their everyday lives. Although there have been recent review papers discussing CAs in healthcare [94–100], the current CA is the first (to the best of the authors' knowledge) that takes over the role of a scalable social actor framed as a scalable assistant of a healthcare professional that mediates communication among various relevant stakeholders in the context of chronic disease management. For this purpose, the MAX CA uses several communication channels (e.g. in-app chat, email, and SMS) and, therefore, "lives" not only on a smartphone in the pocket of a patient but is rather omnipresent, i.e. MAX appears also on the phones of family members (e.g. via SMS) or on desktop or tablet computers of healthcare professionals (e.g. via emails and via the web-based MAX cockpit). It is also the very first time that this type of mediating CA was assessed not only in the lab, as many other CAs [94], but in a realistic longitudinal intervention field study in a complex socio-technical system with various stakeholders.

The design of MAX was driven by an interdisciplinary effort that resulted in a conceptual model with intervention components informed by human behavior and experiential learning theories [61,65,66], findings from technology acceptance research [49,51,58,101], and prior experiences of the authors with CAs that support healthcare professionals and young adolescent patients [67,68].

The results of a first feasibility study indicate an overall positive evaluation with respect to the reach of the intervention (i.e., 49.5% of 99 young patients approached did install the app and started to interact with the MAX CA), the strong working alliance between patients and the MAX CA, and a high acceptance of the intervention by all relevant stakeholders (i.e. healthcare professionals, young patients and their supporting family members). Compared to very similar CA research targeting childhood obesity [67], physical inactivity [77], or the management of chronic pain [17], the current intervention resulted in a high overall therapeutic goal achievement rate (75.5%) but also in improved asthma knowledge test scores and behavioral skills (i.e. no identified inhalation mistakes anymore after the feedback from healthcare professionals). Moreover, the MAX CA was able to motivate family members to support the young patients most of the time when asked (97.8%). In terms of human effort and responsiveness of healthcare professionals, it can be concluded that the MAX intervention is scalable since most of the conversational turns (99.5%) were conducted by the patients and the MAX CA. After the app onboarding process of which takes an average of 15 minutes, healthcare professionals had, on average, only one conversational turn with the patients via the manual chat channel of the MAX app when they provided their personalized feedback regarding the inhalation technique. In addition, it took them less than four minutes to assess the inhalation technique and three days to deliver that feedback to the patients. For each patient, this intervention involved an average of 20 min of human effort, 10 automated SMS including 3 reminders, and additional costs for gift vouchers including lottery winnings. We minimized the risk for smartphone addiction [76] by limiting the amount of possible sessions to one per day and further including active exercises outside the digital environment of the app to increase social interaction and to counteract increasing smartphone usage among children [102].

The qualitative feedback suggested a number of valued and important features, as well as challenges and potential improvements, of the intervention. Combining results from each question of the quantitative analysis and considering the importance and frequency mentioned, several aspects must be discussed and eventually improved in future versions. First, technical issues should be limited as the reach and effectiveness of such intervention is dependent on a problem-free operation. This requires, based on the experience gathered with the MAX intervention, a better understanding and analysis of the technical infrastructure of the healthcare professionals' institutions (e.g. simple-to-use patient access to broadband Internet via WIFI in hospitals). Even though the text-based CA was perceived as positive and engaging, participants indicated that the CA had too many pre-defined answer options. It was suggested [103] that CAs can be influential and engaging for young patients and that open text answers are much appreciated. However, privacy issues with CAs and open text answers were pointed out by prior work [104] as CAs that are responsive to such inputs could potentially and unintentionally retrieve more and more personal information.

Limitations and future work

The present study was designed as a feasibility study with a limited number of participants. It therefore provides the basis, not the end solution, for future activities in the field. Based on our limited sample, it is clear that the results are not representative and must be interpreted with caution. Further, only healthcare professionals from four hospitals (e.g. pediatric pneumologists) and two cantonal patient organizations of the Swiss Lung Association participated in this study. That is, it is not clear whether and to which degree the MAX intervention would work the same way with other relevant healthcare professionals, such as a general practitioner. These non-specialized healthcare experts may require significantly more time for the assessment of the inhalation video clips or would not have the expertise to do so without additional educational efforts. Another limitation of the current study pertains to the inductive open coding of the interviews was performed by one author only (SH), resulting in a certain bias of the qualitative results. Also, since the social support assessment was self-reported by the young patients and linked to additional points for the MAX intervention (to increase chances to be among the winners), it can be assumed that the supportive involvement of family members was overestimated. Finally, the MAX cockpit and, with it, the patient data, was not integrated into hospital information systems or the information system of the patient organization. Specifically, some data had to be stored in a redundant way (e.g. contact number, names of the patient) in the MAX system and, thus, probably resulted in an overestimation of efforts (e.g. the duration of the onboarding process).

The MAX intervention itself can be improved in several ways. First and foremost, as a next step according to the multi-phase optimization strategy [57], we suggest conducting optimization trials to identify intervention components that have a positive and significant impact on the cognitive and behavioral skills. Here, we suggest assessing those components that are more costly, i.e. intervention components that involve human effort. The resulting "effective" intervention package should then be assessed in a final RCT with relevant distal health outcomes, such as asthma control or quality of life. Moreover, we suggest incorporating a digital biomarker that is able to predict life-threatening events (e.g. asthma attacks). For example, there is evidence that the number of nocturnal cough events is negatively correlated with asthma control [105,106], and that nocturnal cough in adult asthma patients can be detected reliably with the microphone of a smartphone [89,107]. Having such a digital biomarker may also help to further develop the MAX intervention as a just-in-time adaptive intervention (JITAI) [108,109]. In such an intervention, after the basic psychoeducational coaching sessions are finished, the MAX CA would message patients only when a specific state of vulnerability [89] and state of receptivity is identified [110]. In addition, and consistent with the JITAI approach, one may also consider an intervention component that monitors medication intake and sends out medication reminders in case no inhalation events were detected. The systematic assessment of inhalation video clips by healthcare professionals can also be used as a label for the correct use of inhalation devices. Additionally, taking advantage of those labels and the latest advances in video classification methods for activity detection [111] may enable the automatic assessment of inhalation technology. As a consequence, this may reduce the time required to assess the inhalation technique and may even increase the quality of the assessments. Furthermore, since there was a clear difference in the assessment time of the inhalation video clips between the primary and secondary care settings, a dedicated and specialized expert may be considered for this task. However, this addition may undermine the working alliance between the patient and the primary point of contact, i.e. the healthcare professional who takes care of that patient. Finally, future deployments of MAX must consider a robust, technical infrastructure with a clear focus on the easiest WIFI access possible during on-site consultations to guarantee an efficient download of the app and onboarding process.

In case none of these additional intervention components or studies are considered, estimates of the MAX project team indicate that the development of the current MAX intervention into a "product" would cost another 100,000 USD. General ongoing costs include keeping intervention content updated according to recent asthma management guidelines (costs approximately 10,000 USD every three years) and maintaining technical software (costs approximately 10,000 USD per year).

Comparison with prior work

Digital health interventions for asthma include numerous mobile health applications that provide patients with information and help them track symptoms or medications, often using a gamification component [45–47]. A systematic review of 15 different digital interventions for pediatric asthma management showed that 87% improved medication and behavioral adherence while 53% demonstrated improved health outcomes [112]. Although these mobile health apps offer a range of features (e.g. automated personalized texts, interactive websites and online modules) to inform patients about asthma, they have not included scalable text-based healthcare CAs to support communication with healthcare professionals. Previous studies in other health domains have demonstrated promising results in using CAs to improve outcomes, such as promoting physical activity for childhood obesity [103,113]. By applying a scalable CA for asthma specifically, the MAX intervention can provide greater healthcare professional interaction at reduced cost, which has been a key concern in past asthma interventions [112]. A unique advantage of MAX is its use of a three-component intervention that involves healthcare professionals, the digital assistant MAX, and family members to support young patients as they work on specific tasks to expand asthma knowledge and improve behavioral skills.

Conclusions

In this study, we have shown that CAs framed as digital assistants of healthcare professionals have the potential to improve cognitive and behavioral skills in chronic disease management, with asthma in children as one specific example. We have demonstrated that CAs can take over the role of a mediating social actor in a complex healthcare setting with various stakeholders and deliver a digital health intervention in a scalable way into the everyday life of patients and their family members. Consistent with the novel JITAI approach, this study provides further insights into the use of CAs that, in the future, may "listen into" states of vulnerability and states of receptivity and, as a result, direct relevant information to appropriate individuals, be it the patient itself, a romantic partner, family member, a nurse or medical doctor. We therefore envision a future in which scalable CAs act like a grand maestro, who dynamically directs an orchestra through a symphony of life based on what the various musicians offer and he or she perceives and, with each repetition, gets better and better in doing so.

Conflicts of interest

TK, TS, SH, FB, EF, and FW are affiliated with the Center for Digital Health Interventions (CDHI) (www.c4dhi.org), a joint initiative of the Department of Management, Technology and Economics at ETH Zurich and the Institute of Technology Management at the University of St. Gallen, which is funded in part by the Swiss health insurer CSS. The MAX intervention and study was co-funded by CSS and the Swiss Lung Association. TK is also cofounder of Pathmate Technologies, a university spin-off company that creates and delivers digital clinical pathways and has used the open source MobileCoach platform for that purpose, too. Pathmate Technologies received funding from the Swiss Lung Association to develop the MAX app and the web-based MAX cockpit for healthcare professionals based on the MobileCoach software. The developed generic software modules were made open source in the latest version of MobileCoach, too, by CDHI. Neither CSS, nor the Swiss Lung Association, or Pathmate Technologies were involved in any way in the data analysis or manuscript preparation process. None of the healthcare professionals were involved in the data analysis in any way. Neither CSS nor Pathmate Technologies were involved in any way in the study design, too. All other authors report no conflicts of interest.

Abbreviations

BCT: Behavioral Change Technique
CA: Conversational Agent
JITAI: Just-in-time adaptive intervention
JMIR: Journal of Medical Internet Research
RCT: randomized controlled trial
SMS: Short Message Service
SSL: Secure Sockets Layer
USD: United States Dollar
WIFI: wireless LAN

Multimedia Appendices

MMA 1: Overview intervention coaching sessions and schedule (long)
MMA 2: Overview intervention coaching sessions and schedule (short)
MMA 3: Cockpit for healthcare professionals
MMA 4: Physical onboarding card
MMA 5: Study recruitment assessment (German)
MMA 6: Study recruitment assessment (English)
MMA 7: Screenshots MAX App
MMA 8: Video Onboarding, quiz, in-app video
MMA 9: Videoclip patient inhalation (German)
MMA 10: Screenplay MobileCoach Asthma (German)
MMA 11: Screenplay MobileCoach Asthma (English)
MMA 12: Study flyer original (German)
MMA 13: Study flyer (English)
MMA 14: Study information for healthcare professionals (German)
MMA 15: Study information patients and family member (German)
MMA 16: Study consent patient and family member (German)
MMA 17: Survey instruments
MMA 18: Health Literacy quiz items (English)
MMA 19: Qualitative Feedback
MMA 20: Videoclip explanation inhalation videoclip assessment

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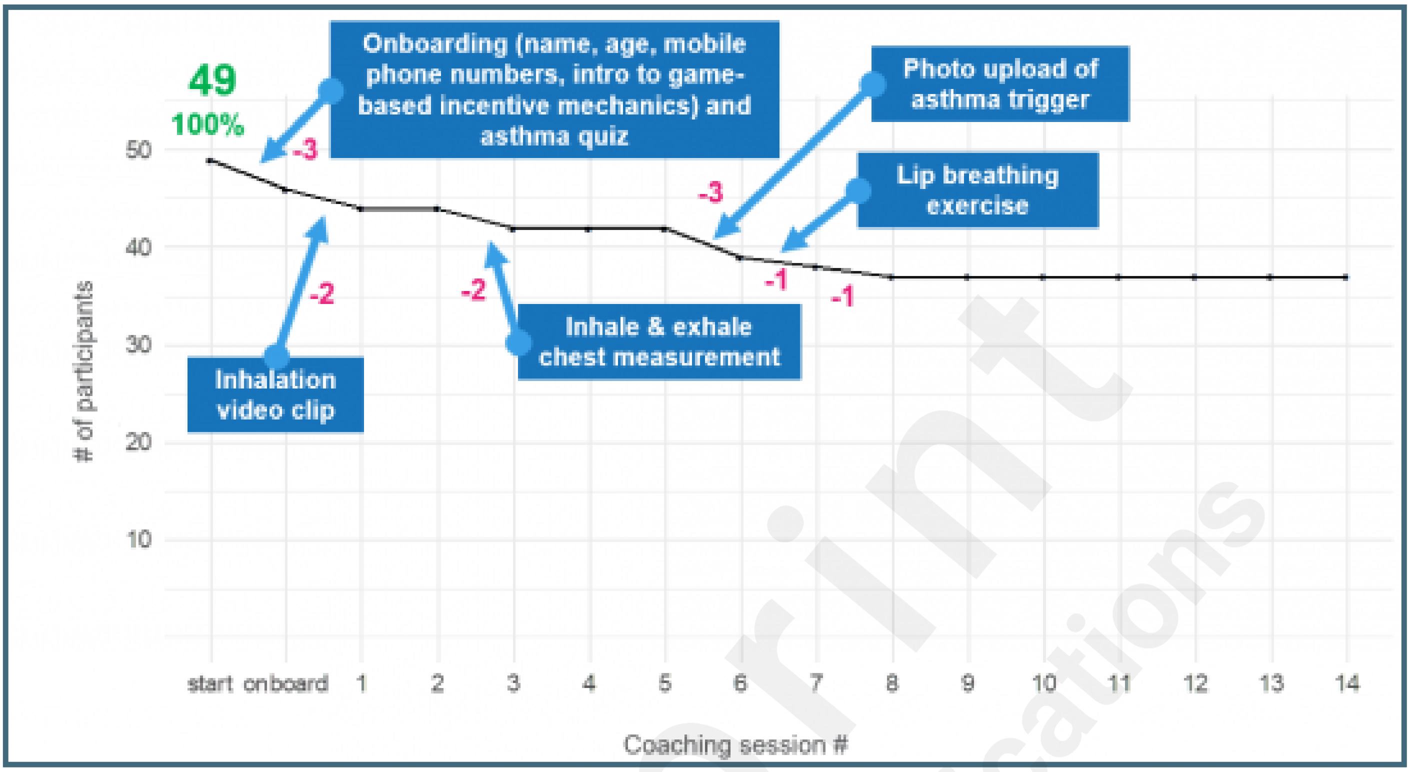
Supplementary Files

Figures

Drop outs.


49
100%
Onboarding (name, age, mobile phone numbers, intro to game-based incentive mechanics) and asthma quiz
Photo upload of asthma trigger
Lip breathing exercise
Inhalation video clip
Inhale & exhale chest measurement
-3
-2
-2
-3
-1
-1
# of participants
10
20
30
40
50
start
onboard
1
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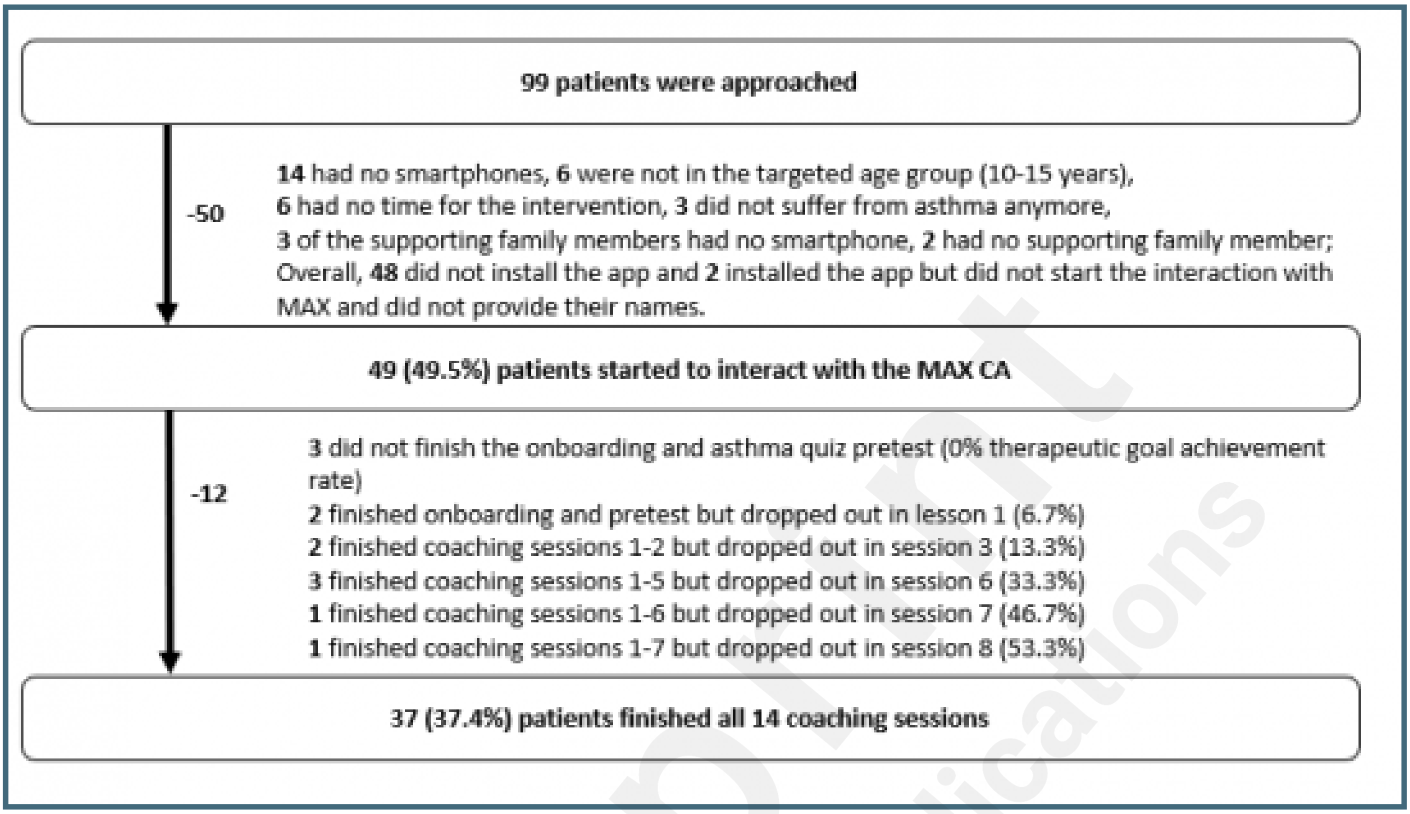
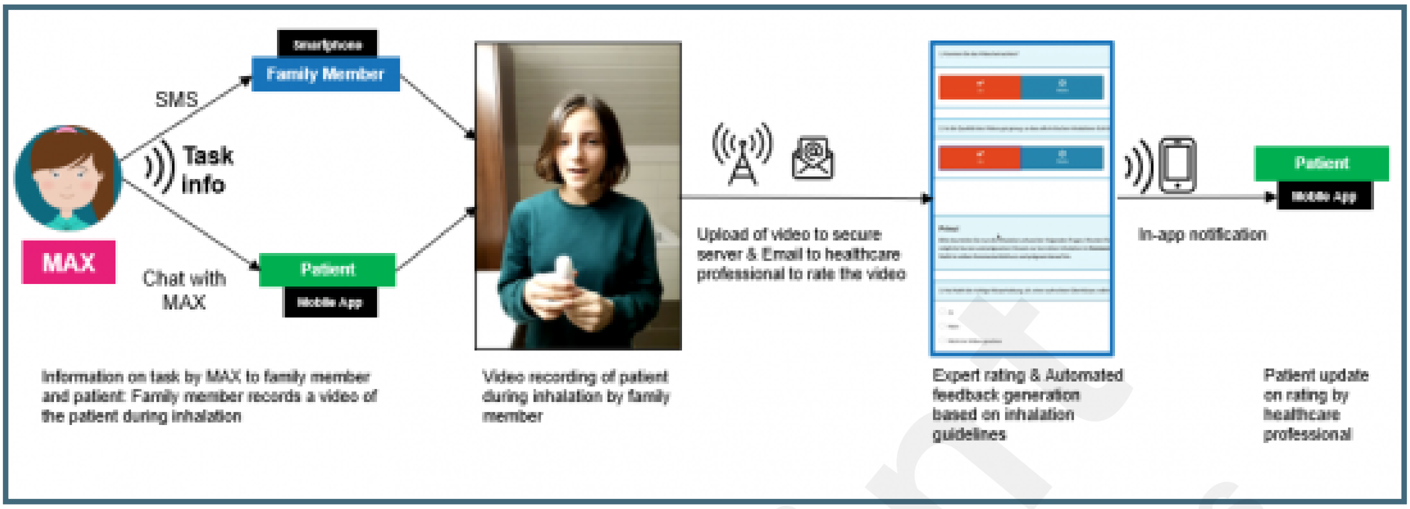
Coaching session #

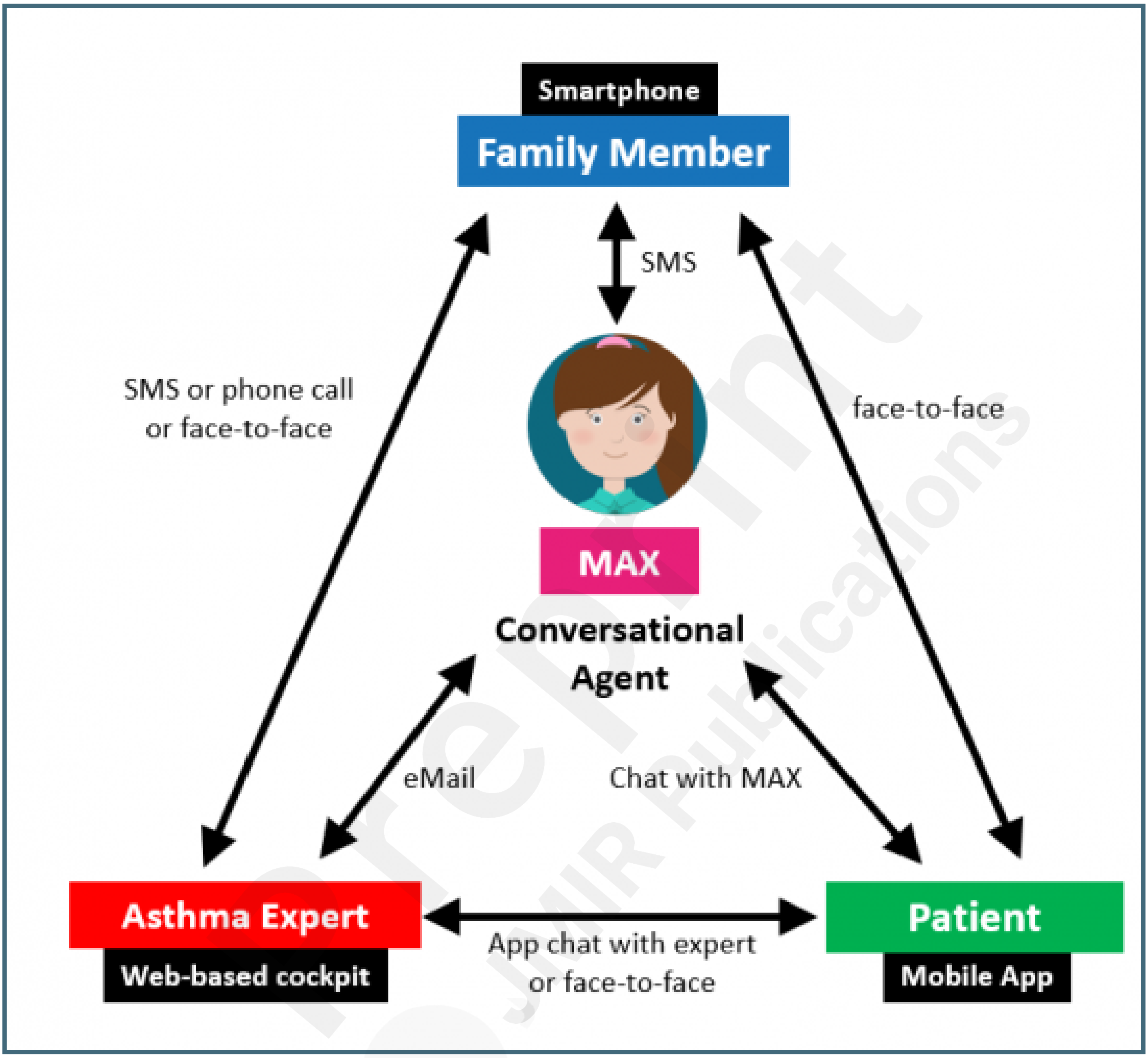
Adherence Rate and Therapeutic Goal Achievement.



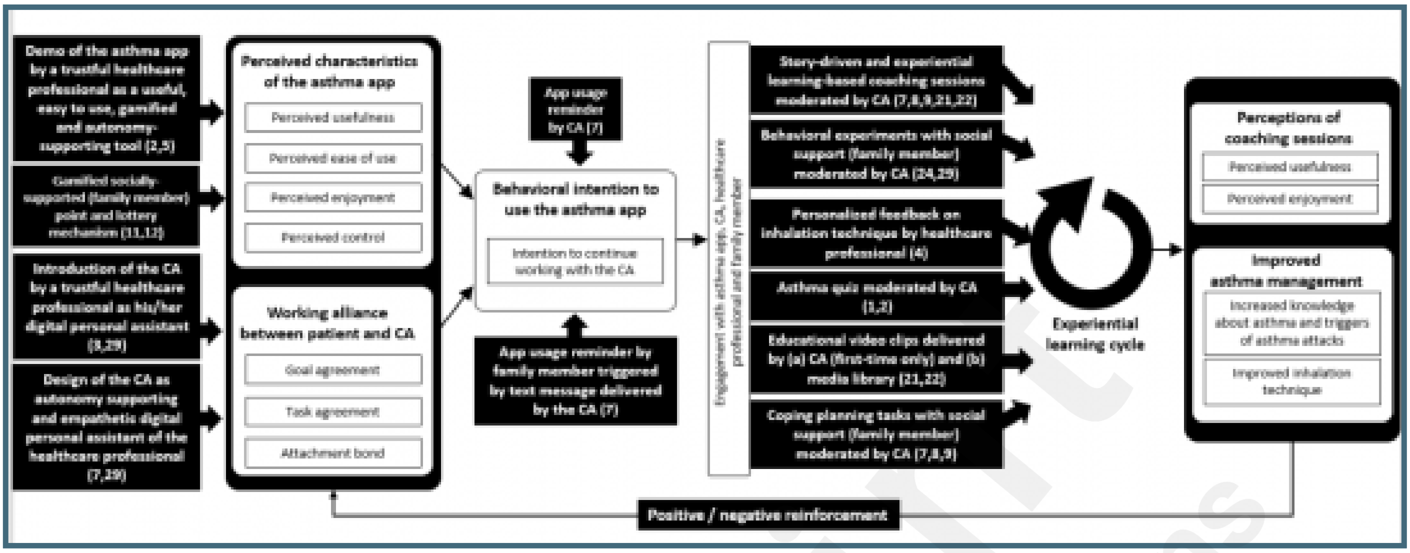
Session Example.



Stakeholders.



Conceptual Model.



Multimedia Appendixes

Study information for healthcare professionals (German).
URL: https://asset.jmir.pub/assets/3957149024c10d01aaaacc635909daae.pdf

Videoclip explanation inhalation videoclip assessment.
URL: https://asset.jmir.pub/assets/c809dac6f617da826fedef98b77abb64.mp4

Qualitative Feedback.
URL: https://asset.jmir.pub/assets/22d9c95530b55f10df687c8dbd64bf50.pdf

Health Literacy quiz items (English).
URL: https://asset.jmir.pub/assets/0ccab02e9067e9aa1812d49e2a58fba9.pdf

Survey instruments.
URL: https://asset.jmir.pub/assets/acc96417e103665e2aaab1dee80965e8.pdf

Study consent patient and family member (German).
URL: https://asset.jmir.pub/assets/2f532f9236a253da34759ce97523102b.pdf

Study information patients and family member (German).
URL: https://asset.jmir.pub/assets/ce85418bbf160558747801224ca2b53a.pdf

Overview intervention coaching sessions and schedule (long).
URL: https://asset.jmir.pub/assets/3afb908768c4c286135834ee265a7325.pdf

Overview intervention coaching sessions and schedule (short) .
URL: https://asset.jmir.pub/assets/1fc0d60bb346bead3ba42d854dc370dc.pdf

Study flyer original (German).
URL: https://asset.jmir.pub/assets/1e9bfe81c56964cacc8ddd852fcf6e48.pdf

Screenplay MobileCoach Asthma (English).
URL: https://asset.jmir.pub/assets/7a6f6d4154264d2e4b4c48d3c8e24d67.pdf

Screenplay MobileCoach Asthma (German).
URL: https://asset.jmir.pub/assets/570f0eee747a47aeaf711e3f3e0a540a.pdf

Videoclip patient inhalation (German).
URL: https://asset.jmir.pub/assets/5fb6842ce2e5594f27cb6c5fbf4ddd84.mp4

Video Onboarding, quiz, in-app video.
URL: https://asset.jmir.pub/assets/e3749212b4bff2f22acab27859c56bc8.mp4

Screenshots MAX App.
URL: https://asset.jmir.pub/assets/9d290d5406e0ce300023165812740505.pdf

Study recruitment assessment (English).
URL: https://asset.jmir.pub/assets/7e35628bbbe8306ebf6213c7e5d38177.pdf

Study recruitment assessment (German).
URL: https://asset.jmir.pub/assets/e24c206474f2c97ff54ca2847e0d466f.pdf

Physical onboarding card.
URL: https://asset.jmir.pub/assets/c5ba9bc830d7865657173d88b1653dd5.pdf

Cockpit for healthcare professionals.
URL: https://asset.jmir.pub/assets/c1bbd486dafe2fde6c9aab836951b4e8.pdf

Study flyer (English).
URL: https://asset.jmir.pub/assets/c1c22189b14ce61da85c80a7ce8a5935.pdf