The design, development, and utilization of *breathe*: A patient-centered mHealth system that supports asthma self-management

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Abstract

Background

Uncontrolled asthma poses substantial negative personal and health system impacts. Web-based technologies, including smartphones, are novel means to enable evidence-based care and improve patient outcomes.

Objective

To design, develop, and assess the utilization of an asthma collaborative self-management platform (breathe) using content based on international evidence-based clinical guidelines.

Methods

Well-established user-centered design methods, combined with ISO-certified development processes were used to design and develop breathe. The data collection protocol collected user data for 12 months, with clinic visits at baseline, six, and 12 months. Utilization outcomes included user interactions with the platform, user impressions, self-reported medication use and asthma symptom profile, reported peak flow measurement, the delivery and response to email reminders.

Results

We designed and developed breathe as a web-based mHealth platform accessible on smartphones, tablets, or desktop. The system enabled collaborative self-management and self-monitoring of asthma patients through: (1) assessment of asthma control, (2) real-time access to a dynamic asthma action plan, (3) access to real-time environmental conditions, and (4) risk-reduction messaging.

We enrolled 123 participants with a mean age of 45.2 years (Standard deviation (SD) ±15.8). A majority were female (72.5%), had a smartphone (66.7%), and had a mean Asthma Control Test score of 18.3 ± 4.9. Participants indicated a strong belief that the program had improved their ability to manage asthma and the tool scored 71.1 ± 18.9 on the System Usability Scale. The platform sent 7.96 reminder e-mails per patient per week (pppw), patients accessed breathe 3.08 times pppw, journaled symptoms 2.56 times pppw, reported medication usage 0.30 times pppw, and reported peak flow measurements 0.92 times pppw. breathe calculated patients’ action plan zone of control 2.72 times pppw, with patients being in the green (well-controlled)
zone in 48% of the total calculations. Usage analysis showed that 60% of the participants used the app at week 4 and only 30% by week 45.

**Conclusions**

*breathe* was designed and developed to enable patients to collaboratively self-manage their asthma. Strong usage is seen at the intervention’s initiation, followed by a reduction potentially due to the high proportion of well-controlled individuals with asthma, infrequent clinician surveillance, lack of a strong engagement technique, and patients achieving the right “digital dose” of the intervention. Usage patterns observed during this intervention provide important learnings for future mHealth developments regarding reminder design and sustained effects, ideal times for interaction with patient, surveillance effect, and engagement methods matched to patient health characteristics.

**Keywords:** asthma; self-management; data-driven design; user centered design; collaborative care; mhealth; mobile health; user evaluation; usability
Introduction

Asthma is a common chronic disease that poses a serious global health problem. In Canada alone, asthma affects 10.8% of Canadians [1]. Globally, the Global Burden of Diseases, Injuries, and Risk Factors Study estimated that 339 million people suffer from asthma, where asthma is the most common chronic disease among children [2,3]. Fifty percent of patients with asthma are uncontrolled, leading to substantial personal and health system impacts [4–8]. In Canada, there are 150,000 emergency room visits and 60,000 hospitalizations triggered annually by asthma [9]. National and international guidelines, and systematic review evidence, recommend collaborative self-management, including a written asthma action plan, patient education, and regular clinical review [10–13]. These have been shown to improve these important patient and health system challenges, by reducing hospitalizations (relative risk [RR] 0.64; 95% CI 0.50 to 0.82), emergency room visits [RR 0.82; 95% CI 0.73 to 0.94], unscheduled visits to a doctor [RR 0.68; 95% CI 0.56 to 0.81], absenteeism [RR 0.79; 95% CI 0.67 to 0.93], nocturnal asthma symptoms [RR 0.67; 95% CI 0.56 to 0.79], and significantly improve quality of life [13].

Moreover, a majority of patients prefer an active or collaborative role in their asthma management, particularly in the context of an asthma exacerbation [14,15]. Despite this strong evidence, these patient preferences, and consistent recommendations in international guidelines [10–12], collaborative self-management continues to be available to only a minority of patients (2-11%) [5,16]. For these reasons, asthma is a chronic disease well suited for an examination of the transformative promise of smartphone mobile health apps (mHealth apps) in support of collaborative self-management.

Smartphones have become ubiquitous and mHealth apps have the potential to transform elements of chronic disease management [17,18]. mHealth apps offer new opportunities for access to care, disease specific education, monitoring and disease management, personalized goal setting, adherence reminders, and communication. However, mHealth app development is largely unregulated and proper focus on user-centered design is lacking [18,19]. A systematic assessment has revealed unreported product development and design standards, content inconsistent with evidence-based standards, high app turnover, unreported safety profiles, and inconsistent implementation of privacy and security measures [20]. Further, despite a decade of mHealth app development, there remains a limited body of evidence demonstrating improved health outcomes with apps [20–22]. Requisite to the success of smartphone apps as new tools in the management of chronic diseases are a commitment to, and evidence of, user-centered design, development, and evaluation to ensure privacy, efficacy and safety.

Currently, there are three published randomized controlled trials evaluating patient-facing, multi-functional asthma apps developed to support collaborative self-management. Liu and colleagues [23], showed increased quality of life, increased use of controller medications,
improved lung function (8%), and decreased emergency service use. Merchant and colleagues demonstrated the effectiveness of the Propeller Health Asthma Platform at reducing the use of short-acting β-agonist (SABA) by 0.41 activations per day (vs. 0.31 control), increasing the number of SABA-free days by 21% (vs. 17% control) [24]. Conversely, Ryan and colleagues found that mobile phone-based monitoring did not improve asthma control or patient self-efficacy compared to a paper based monitoring system [25]. Our experience with an asthma app prototype in a recent pilot study revealed a high level of satisfaction with the app (80% of users viewed the app positively, with the majority wishing to continue using the app after the study), regular participation in self-management [26], with improvements in asthma-related quality of life. However overall, the efficacy of asthma collaborative self-management smartphone apps remains uncertain [26].

We sought to design and develop a multifunctional, collaborative self-management mobile health (mHealth) platform, based on clinical content from international evidence-based guidelines, following a user-centered design process, and to then evaluate its utilization to inform iterative product improvement.

Methods

The breathe development program was structured in two main project phases: (1) the design and development process for building the breathe mHealth platform including architecture, design, platform content, functional elements, user experience and utilization; and (2) an evaluation of the patient outcomes by randomized controlled trial (RCT) and by a population-based cohort study. The utilization data reported in this manuscript is derived from the intervention (breathe) arm of the RCT. The RCT has been completed and some of the results published in abstract form [27].

Design and Development of breathe

breathe Development Specifications

Specifications were developed collaboratively with Canada Health Infoway and included: (1) a user-centered web-based asthma self-management platform available on any web-enabled device including mobile phone browsers and standard web browsers on laptop, desktop, tablet to ensure equitable access of the application; (2) patient access to their personal health information and electronic health records through connectivity with TELUS health space®, which was a localized version of Microsoft Health Vault® (web-based personal health record developed by Microsoft); (3) alignment with national and provincial clinical and electronic health (eHealth) priorities, as per the Canadian Thoracic Society (CTS), Ontario Lung Association (OLA), eHealth Ontario (a provincial agency tasked with the implementation of the Ontario’s public Electronic Health Record System), and the Ontario Ministry of Health and Long-Term Care; and (4) scalability to the provincial level and ability to be leveraged by other jurisdictions within Canada.

**The Development Team**
breathe was developed by the Centre for Global eHealth Innovation at the University Health Network in collaboration with clinicians, researchers and scientists from Western University, Queen’s University, Hospital for Sick Children, and the University of Toronto. The Centre is certified under ISO 13485, an international quality management system, to ensure the safety and quality of innovations. The mHealth platform development was guided by a 16-member interdisciplinary steering committee including asthma expert respirologists, certified asthma educators, population health scientists, knowledge translation experts, and eHealth experts. These experts were informed by four working groups: benefits evaluation, technical, consumer engagement, and clinical. Working groups were comprised of a few members of the steering committee, along with additional individuals who contributed specific expertise such as consumers, IT professionals, and clinicians.

**The Design Process**
breathe (Figure 1) was designed using well-established user-centered design (UCD) methods [17,19,28], ensuring that the input and requirements of final users of the technology (patients, caregivers, physicians) were included in the design process. The iterative UCD process included 11 interviews, and five usability testing and cognitive walkthrough cycles [19,28]. Initial user research provided the necessary evidence for the conceptualization and initial prototypes of the intervention. Multiple cycles of cognitive walkthroughs and usability testing allowed the breathe team to improve the design based on user feedback and observed issues, focusing on the needs of the platform’s final users and avoiding the paradoxes of expertise [19]. The final design of the platform ensured that functionality was aligned with clinical needs and patient preferences and limitations.
Privacy and Security
A privacy impact assessment was completed by MD+A Health Solutions, an independent third-party company, regarding all aspects of the breathe project including business processes for implementation of the breathe application, evaluation activities, technical implementation, and support processes. A threat risk analysis was completed by iSecurity. breathe achieved Canada Health Infoway's Consumer Health Application Certification, confirming conformity with national privacy, security and interoperability standards.

Evaluation of the Patient Experience, Platform Usability, and Utilization

Patient Recruitment
The utilization data reported in this manuscript is derived from the intervention (breathe) arm of the RCT designed to evaluate patient outcomes [27]. Participants were recruited from six primary care and two specialty asthma clinics in Ontario, Canada. A convenience sample of patients self-identified after viewing posters in the clinic or were invited to participate by clinic staff. The participating clinics were geographically distributed – e.g. north, east, southwest and central Ontario – with a range of urban and rural communities. The study received IRB approval and all patients signed a written informed consent prior to randomization (Western University HSREB 102842, Queens University HSREB 6007261, University Health Network REB 12-0102-AE and 12-0102-AE_Amendment). All participants randomized to breathe had a baseline onboarding clinic visit where they were provided with breathe accounts, received a brief orientation, and completed a six and 12-month follow-up visit.
Platform Usability, Consumer Satisfaction and Confidence

Two customized consumer satisfaction questionnaires and the standardized System Usability Scale [29] were administered at six and 12 months post-enrollment.

Measuring Platform Utilization

*breathe* was designed to collect usage data (in-app analytics) to enable data-driven design and evaluation. Information flowing through the *breathe* data server was logged and used as part of this evaluation. The *breathe* server tracked: medications prescribed to patients, self-reported medication use, peak flow actual compared to personal best or normal, action plan zone of control, general access, and e-mail notifications sent by the system. Each entry to the database was identified with a unique user ID and time stamped to enable further analysis.

Results

*breathe*: mHealth Platform Architecture

*breathe* is a web-based bi-directional mHealth platform that utilizes HTML5 and responsive design allowing a single version of the platform to be accessible on any device (smartphone, tablet or personal computer) (Figure 2). *breathe* interfaces with TELUS health space®, where it receives up-to-date medication and peak flow rates from the integration of clinical data repositories (electronic medical records). As well, *breathe* retrieves real-time environmental conditions directly from Environment Canada, which include current and forecasted weather conditions, in addition to the Air Quality Health Index (AQHI) with relevant risk-reduction health messaging from Health Canada. The AQHI is a simple 1-10 scale designed to help individuals understand air quality, the impact of poor air quality on their health, and what actions to take to minimize health risks [30].

*breathe*: Functionality

The healthcare provider developed an 'asthma app prescription' in a collaborative triad of patient, provider, and app. The healthcare provider determined the patient’s asthma medications, their individualized action plan by zone, and peak flow parameters for control zone calculations (if applicable). The *breathe* platform did not advise on the selection of medications and did not create the action plan. This remained a physician responsibility. Integrating with TELUS Health Space® offered patients the option to share *breathe* data with family members and/or other healthcare providers, which could be accomplished through the Health Space® online profile. The *breathe* features can be seen in the Multimedia Appendix 1. Each of these features was designed to engage users and to collect relevant data to support self-management, as described below:
Figure 2: Architecture of the breathe platform (OLA – Ontario Lung Association, AQHI – Air Quality Health Index, CDR – Clinical Data Repository). In cases where peak flow was part of the action plan, peak flow ranges were entered by the provider. Patients were responsible for entering peak flow measurements as measured.

Journal – The Journal feature allows patients to track daily symptoms, record reliever and controller medication usage, and to log peak flow measurements. The historical review feature allows users to look back at previous journal entries and peak flow values entered.

Your Zone – The journal entries feed an integrated asthma control algorithm based on the CTS Asthma Guidelines [10,12] that analyses patient inputs and immediately advises the patient of their current zone of control: (1) green zone – in control, (2) yellow zone – uncontrolled, or (3) red zone – dangerously uncontrolled. The zone of control assessment is paired with the actionable recommendations from patients’ personalized asthma action plan. The zone of control is dynamic, immediately updated with any new journal entries and re-sets after the action plan has been executed, ensuring a tailored and customized intervention to the patient [31].

Trends – Data visualization and analysis of several trends, including identified triggers, control zone, and peak flow values was available to users. An example of the usefulness of this feature is that trigger frequency reported back to patients may enable patient insights into which triggers to avoid in the future.

Environment – This feature provides real-time current and forecast of location-specific (based on users’ input about their location) environmental conditions including temperature, humidex, weather forecast and the Air Quality Health Index with specific poor air quality risk-reduction health messaging.
Account – This feature includes a variety of options including setting a time and email account to receive emailed medication adherence reminders, and setting a location for location-specific environmental information. E-mail adherence reminders were automatically generated based on predefined rule-based logic including a welcome e-mail, "check-in" e-mails for users not accessing the platform within seven days, and daily adherence reminders for controller medications.

A demonstration of how the breathe platform works can be found in the Canada Health Infoway website, with a detailed description of functionalities and platform capabilities (https://www.infoway-inforoute.ca/en/component/edocman/resources/videos/innovation-patient-access/1908-breathe-a-canadian-asthma-app).

breathe: Patient Population
We recruited 342 patients into the RCT between October 31, 2012 – March 31, 2014, of whom 138 were allocated to the breathe intervention arm. Complete platform utilization data was available in 123/138 (89.1%) participants. The majority of the participants were women (100, 72.5%), mean age 45.3±15.8 years, and 134 (97.1%) were Caucasian. Of these participants, 92 (66.7%) had a smartphone and the majority (82.6%) reported being "comfortable" or “very comfortable” using it. Patients recruited had a mean Asthma Control Test score of 18.3 ± 4.9, suggesting well to somewhat well-controlled baseline asthma [32].

breathe Usability, Patient Satisfaction and Confidence (12 month data)
Usability was evaluated by the System Usability Scale, a validated composite measure which is scored from 0 to 100, with higher scores representing greater usability (Table 1). The breathe system scored at 71.1±19.9 at 12 months indicating good usability, as defined by Bangor et al. [33]. In five-point Likert scale responses, 1-very difficult, 3-don’t know/neutral, 5-very easy, breathe was ranked high in usability (4.3±1.0), application accessibility (3.9 ±1.3), ability to search and review action plan information (4.1±1.1), and application navigation at (4.2±1.1).

Satisfaction was evaluated using five-point Likert scale responses, 1-strongly disagree, 3-don’t know/neutral, 5-strongly agree. There was a high level of satisfaction with the overall care of asthma in the clinic (4.7±0.4) and access to the healthcare team (4.7±0.5). Participants felt that the care program (including the platform and all other aspects of their asthma care) had improved their ability to manage asthma (4.2±1.0) and improved their overall asthma control (4.2±1.0). Patients were confident that breathe was correct when it presented the patient’s asthma action plan zone of control (3.7±1.1). Participants were neutral to “continue to use the application after the study” (3.4±1.3). The results reported above correspond to the 12-month data as minimal differences were observed between the 6-month and the 12-month data (Table 1). On the same Likert response scale, patients responded the the questions, “I have become a more active participant in the management of my asthma” and “My access to the healthcare
team has been enough to help me learn how to manage my asthma” with a mean of (4.3±0.9) and (4.6±0.6) respectively.

**Actual breathe Utilization**
The 123 patients in the intervention arm accessed breathe 19,678 times (3.08 times pppw - per patient per week), reported symptoms in their diary 16,357 times (2.56 times pppw), reported medication use 1,922 times (combined use of reliever and controller; 0.30 times pppw), and reported peak flow measurements 5864 times (0.92 times pppw). Total counts can include patients accessing the platform multiple times in the same day.

*breathe* calculated patients’ action plan zone of control 17,396 times (2.72 times pppw). Patients were most often in the green zone of control (48% of calculations), followed by yellow zone (24%) and red zone (6%). In 22% of the calculations, breathe did not have enough information to return a zone of control back to the patient based on the programmed algorithm in the breathe platform (Figure 3).

*breathe* sent 50,939 e-mails (7.96 times pppw) to remind participants to take their controller medications or to return to the platform after seven-days of no usage.

Tracking patient log-ins to the platform demonstrated a fall in use within the first 4 weeks of initiation and thereafter a standard decay in usage (Figure 4), whereby 60% of the participants used the platform weekly initially and only 30% used the platform in week 45.

Further utilization analysis demonstrated patterns of use that related to patient behaviour, breathe functionality, or the interaction of both. **Time of Day:** Analyzing logins by time of day revealed two periods of increased utilization (Figure 6). First, there was higher platform use between 5:00 am and 10:00 am, which corresponds to the time of the day when most patients are waking up and preparing for their day. Second, there was a dramatic spike in utilization just after 7:00 pm, the time of day when the breathe system e-mail reminders were automatically sent by the application server. This finding was sustained each month over the 12 months of the study (Figure 7). **Symptom Reporting:** Evaluation of the Journal functional element within the platform revealed about twice as many reports of good days (a day without symptoms) compared to days with symptoms (Figure 8), which aligns with our expectations for well-controlled asthma. **Scheduled Physician Visits:** Finally, based on controller medication recording, there was an increase in platform utilization in weeks 26 and 52, corresponding to scheduled follow-up visits. (Figure 5).
Table 1: Usability questionnaire.

<table>
<thead>
<tr>
<th>Questions</th>
<th>6 months</th>
<th>12 months (n=119)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q01. I am satisfied with the overall care of my asthma at this clinic.</td>
<td>4.7±0.5</td>
<td>4.7±0.4</td>
</tr>
<tr>
<td>Q02. I am satisfied with the communication between me and the medical staff at the clinic</td>
<td>4.7±0.5</td>
<td>4.7±0.5</td>
</tr>
<tr>
<td>Q03. I have become a more active participant in the management of my asthma.</td>
<td>4.4±0.7</td>
<td>4.4±0.9</td>
</tr>
<tr>
<td>Q04. My access to the health care team has been enough to help me learn how to manage my asthma.</td>
<td>4.5±0.7</td>
<td>4.6±0.6</td>
</tr>
<tr>
<td>Q05. My follow-up appointments are necessary for my asthma care.</td>
<td>4.3±0.8</td>
<td>4.3±0.9</td>
</tr>
<tr>
<td>Q06. The program has improved my ability to manage my asthma.</td>
<td>4.3±0.8</td>
<td>4.2±1.0</td>
</tr>
<tr>
<td>Q07. The program has improved my overall asthma control.</td>
<td>4.1±0.8</td>
<td>4.2±1.0</td>
</tr>
<tr>
<td>Q08. I regularly monitor air quality as part of my plan to keep my asthma under control.</td>
<td>3.2±1.2</td>
<td>3.1±1.3</td>
</tr>
<tr>
<td>Q09. After receiving air quality advisories it is clear what actions I can take to reduce my exposure to air pollution.</td>
<td>3.7±1.1</td>
<td>3.7±1.2</td>
</tr>
<tr>
<td>Q10. It is easy to understand air quality using the air quality health index (AQHI).</td>
<td>4.0±0.8</td>
<td>4.0±0.9</td>
</tr>
<tr>
<td>Q11. The Breath application that was provided to me by the clinic is helpful in the management of my asthma.</td>
<td>3.8±1.1</td>
<td>3.7±1.2</td>
</tr>
<tr>
<td>Q12. I would continue to use the Breath application if it were available to me after the study.</td>
<td>3.7±1.1</td>
<td>3.4±1.3</td>
</tr>
<tr>
<td>Q13. I would continue to use the smartphone AQHI advisory system if it were available to me after the study.</td>
<td>3.6±1.1</td>
<td>3.2±1.2</td>
</tr>
<tr>
<td>Q14. I was confident that when the Breath application was correct when it assessed my asthma zone of control.</td>
<td>3.7±1.1</td>
<td>3.7±1.1</td>
</tr>
</tbody>
</table>

**SYSTEM USABILITY SCALE (possible range 0-100)**

| EVALUATION OF THE COMPONENTS OF BREATHE | 71.2±18.4 | 71.1±19.9 |

**Ease of use (1-very difficult, 3-don't know/neural, 5-very easy)**

| Q01. Overall, how easy was it to use the application? | 4.3±1.0 |
| Q02. How easy was it to access the application? | 3.9±1.3 |
| Q03. How easy was it to navigate through the application? | 4.2±1.1 |
| Q04. How easy was it to add new information? | 3.6±1.3 |
| Q05. How easy was it to search for and review your Action Plan information? | 4.1±1.1 |
| Q06. How easy was it to search for and review your Journal information? | 4.2±1.0 |
| Q07. How easy was it to search for and review Environmental information? | 4.1±0.9 |

**Usefulness (1-not very useful, 3-don't know/neural, 5-very useful)**

| Q08. A. Viewing your Action Plan | 3.9±1.1 |
| Q08. B. Viewing your Zone | 3.9±1.1 |
| Q08. C. Viewing your current medication | 3.7±1.1 |
| Q08. D. Recording Symptoms | 3.8±1.2 |
| Q08. E. Recording Medication Use | 3.7±1.1 |
| Q08. F. Recording Peak Flow | 3.5±1.2 |
| Q08. G. Viewing Air Quality Health Index | 3.7±1.1 |
| Q08. H. Viewing Weather Information | 3.7±1.1 |
| Q08. I. Viewing Trends | 3.7±1.0 |
| Q08. J. Receiving Medication Reminder Emails | 3.4±1.3 |
| Q08. K. Receiving App Adherence Emails | 3.3±1.2 |
| Q08. L. Adjusting Email Settings | 3.1±1.1 |

**Design of components (1-very unsatisfied, 3- don't know/neural, 5-very satisfied)**

| Q10.A. Application readability | 4.2±0.8 |
| Q10. B. Size of characters on screen | 4.4±1.0 |
| Q10. C. Language/Wording | 4.4±1.0 |
| Q10. D. Amount of information on screen | 4.3±0.8 |
| Q10. E. Visual Look/Layout | 4.3±0.8 |
| Q10. F. Sequence of screens | 4.1±1.0 |
| Q10. G. Accessibility | 3.9±1.3 |
| Q10. H. Application speed | 4.0±1.1 |
| Q10. I. Size of buttons | 4.3±0.7 |
| Q10. J. Shape of buttons | 4.3±0.8 |
| Q10. K. Meaning of icons | 4.3±0.9 |
| Q10. L. Size of icons | 4.3±0.8 |
Figure 3: Total calculations of zone of control per month of the intervention calculated from enrollment.
Figure 4: Attrition in breathe use throughout the 12-months of the study.
Figure 5: Self-reported controller medication use.
Figure 6: App use tracked by number of logins by time of day exploring the effectiveness of reminders. Note that automatic app reminders are sent around 7:00pm.
Figure 7: Sustained effect of email reminders on app use over the 12 months of intervention.
**Discussion**

**Principal Results**

We developed *breathe*, a multifunctional patient asthma collaborative self-management web-based platform that supports patients to be active participants in chronic disease management at home, work, and in the community. *breathe* enabled self-management and self-monitoring of asthma patients through assessment of asthma control, real-time access to a dynamic action plan, environmental conditions display, and air quality risk-reduction messaging. We evaluated the usability of *breathe*, actual use of the platform, and user satisfaction to inform a plan for ongoing iterative development.
breathe was designed and developed following well-established user centered design methods to ensure the integration of patient needs into the platform. Evidence-based best practices from the CTS Asthma Guideline and the Global Initiative for Asthma [10–12] guided clinical content, to ensure applicability nationally and internationally. breathe was connected through its mHealth platform to a national personal health record, TELUS health space®, two regional point of service systems (electronic medical records), and to Environment Canada. The platform underwent a privacy impact assessment and threat risk analysis. breathe followed the development specifications set out by Canada Health Infoway, which certified conformity with national privacy, security, and interoperability standards.

Patients had a high level of satisfaction with the individual design components of breathe. They rated breathe as easy to use on the validated System Usability Scale and high for usability on standard Likert scales. A central function of the breathe platform was to present patients with a real-time dynamic action plan based on their symptoms and/or peak flow entries. The application effectively returned a dynamic zone of control calculation back to patients. breathe patients were confident that the calculated assessment was accurate. By objectively measuring control, breathe resolves a long-standing barrier to action plan utilization in the community, the barrier of inaccurate control assessment by patients. Patients that over-estimate control will not activate their action plan as prescribed [5–8].

The breathe mHealth platform was an important communication bridge between providers and patients in the community, delivering 50,939 reminder e-mail messages and communicating asthma control and care recommendation through the platform 19,678 times. An examination of utilization suggests that patients responded to these notifications and patient questionnaires indicate that they had confidence in the care and control recommendations.

Despite high ratings for ease of use and the high degree of satisfaction with the breathe system, actual platform use declined substantially over time, which aligns with reviews describing attrition rates in eHealth deployments [34–37]. The drop out rate identified in this study is a common feature of eHealth applications. In his seminal viewpoint paper “The Law of Attrition” Eysenbach argues the need for a “science of attrition” and recommends that usage metrics be measured, analysed and discussed to identify reasons for attrition [34]. We evaluated factors associated with increased or decreased platform utilization.

Decreased utilization (attrition) in this study may have been related to population and design characteristics including, technology savviness, patients with relatively good disease control, infrequent physician monitoring, or because patients achieved their expected outcomes. We observed that increased utilization was associated with time of day, anticipated physician visits and e-mail reminders.
**Technology savviness:** Although, 61.8% of our population had a smartphone and reported being comfortable or very comfortable with its use, one-third did not have a smartphone and therefore accessed the platform by laptop, desktop, or tablet. The non-smartphone subset may have been less technology savvy contributing to the decline in utilization and particularly may have contributed to the sharp decline in the first 4 weeks.

**Good Disease Control:** Patients in this study had relatively well controlled asthma as indicated by high baseline asthma control tests and a high percentage of Good Days when compared to Episode Days. We did not have a specific engagement strategy to motivate patients to return to the platform when they were feeling well. Failure to engage the users in moments of disease stability has been described by other authors as a critical factor affecting attrition, across diseases [38–40].

**Physician Monitoring:** In this study, patients were evaluated by a physician only twice after enrolment. Infrequent monitoring may have an effect in the increased the attrition rate. Increased breathe platform utilization was associated with upcoming six and 12-month clinic appointments. An increase in eHealth utilization in response to anticipated clinical review has been described by Mohr et al. as supportive accountability [41] and by others [42,43] as a strong factor influencing sustained adherence. The surveillance effect has a direct influence on how engaged patients are with the platform and how much they adhere to the intervention. Along the same lines, eHealth platforms that provide some level of feedback and peer support appear to demonstrate better adherence rates [44]. The need for regular clinical review to motivate platform adherence aligns with the literature supporting written asthma action plans, where efficacy requires regular clinical review [13]. The finding related to increased medication reporting at six and 12 months also suggests that for most of the year, medication use was under-reported. Self-reported medication use may under-report actual use [45]. New Bluetooth enabled smart inhalers that automatically log medication use [46] will be considered in the future development of breathe.

**Patients achieved their expected outcomes:** Patients were satisfied with breathe and at their six month visit agreed or strongly agreed that access to the health care team had been enough to help them learn how to manage their asthma. Thus, it is plausible that at six months, having achieved their personal goals, that patients no longer felt a need to use the platform.

**E-mail Reminders:** Increased breathe platform utilization was associated in time with e-mail adherence reminders. Others have identified reminders as powerful design features to increase adherence and engagement with eHealth platforms [47], to alert participants of important events [18,48], or to alert them of aspects of the treatment they have missed [44]. Although alarm fatigue has been described in long-term interventions, wherein reminders lose their impact over time [49,50], we demonstrated a sustained effect of reminders over the 12 months.
We speculate that the most important attrition factors were good asthma control in the absence of a specific engagement strategy for well controlled patients, that patients had achieved their expected outcomes, and the low number of physician visits. The goal of user-centred design is to create and sustain a certain level of adherence to the platform, as adherence is a pre-requisite to positive behavioral change and improved health outcomes. However, ideal levels of adherence to eHealth and mHealth interventions that support chronic conditions have not yet been established and the ideal “digital dose” is unknown.

**Limitations**

The study and the breathe platform has some limitations the the authors consider important to acknowledge. The population studied was a convenience sample from primary and specialty clinics with a dedicated asthma program and at the time on enrolment, patients had relatively good asthma control. As such, patients’ evaluation of the app and their utilization patterns may not be representative of the general asthma population. Since this project was completed, native applications have largely supplanted web-browser based apps such as breathe. The improved performance of native app platforms may positively impact utilization and reduce attrition. Finally, while we present supporting evidence that the patterns of use identified were related to technology savviness, disease control, physician visits, patient goal achievements, and e-mail reminders, we are not able to confirm a causal relationship.

**Conclusions**

We designed and developed breathe a multifunctional, collaborative self-management mHealth platform, with content based on international clinical practice guidelines, and compliant with national privacy and security specifications. Individuals with asthma reported good usability and high satisfaction levels, responded to breathe communications, and had confidence in the platform's assessment of asthma control. We embedded in-platform analytics, evaluated utilization, and examined the utilization patterns in the context of known patient characteristics. We related increased utilization to physician monitoring and e-mail reminders and attrition to low technology savviness, good asthma control, and to patients achieving their expected goals.

Looking to the future, embedded app analytics combined with data-driven design, will enable real-time evaluation of platform design, enabling innovators to execute design improvements during platform deployment. As we iterate the breathe platform, observations from this study that will inform platform design considerations include: the impact of in-platform or in-person patient-physician feedback to leverage the surveillance effect; the need for a specific strategy to engage patients when they are feeling well and/or to re-engage as they become unwell; a role for automated logging technology (smart/connected inhalers) to capture actual medication utilization; leverage the sustained impact of patient reminders on utilization; and develop the next version of the breathe platform with a native iOS or Android app.
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Conflicts of Interest
The authors declare that some of us are members of advisory boards or equivalent in commercial organizations as AstraZeneca, Novartis, Boehringer Ingelheim, GlaxoSmithKline, and Roche; as well as receiving funding from commercial organizations as AstraZeneca, Novartis, Boehringer Ingelheim, Pfizer, Bayer, and Roche. The work developed in this paper was not funded by any of these companies.
Multimedia Appendix 1: Examples of the various features designed for breathe. These are not actual plans, medications, or patient data, but instead, prototypes of the breathe interface.
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