MAHI: Investigation of Social Scaffolding for Reflective Thinking in Diabetes Management

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ABSTRACT

In the recent years, the number of individuals engaged in self-care of chronic diseases has grown exponentially. Advances in computing technologies help individuals with chronic diseases collect unprecedented volumes of health-related data. However, engaging in reflective analysis of the collected data may be challenging for the untrained individuals. We present MAHI, a health monitoring application that assists newly diagnosed individuals with diabetes in acquiring and developing reflective thinking skills through social interaction with diabetes educators. The deployment study with twenty five newly diagnosed individuals with diabetes demonstrated that MAHI significantly contributed to individuals' achievement of their diabetes management goals (changing diet). More importantly, MAHI inspired individuals to adopt Internal Locus of Control, which often leads to persistent engagement in self-care and positive health outcomes.

ACM Classification Keywords

H.5.2 User-centered design

Keywords

Health care, sense-making, chronic disease management, ubiquitous computing, deployment studies

INTRODUCTION

In the recent years the development of technologies that support individuals in managing their health has become a vibrant, yet challenging, research area. Many of the challenges faced by researchers are a result of significant transformations in doctor and patient attitudes toward health and healthcare and their perception of their respective roles [15]. Traditionally, computing technologies focused on supporting clinical professionals in delivering high-quality care. However, the recent changes in the demographics of industrialized nations, coupled with new advances in computing technologies, are allowing and encouraging lay individuals to adopt increasingly proactive roles in caring for themselves and their loved ones [20].

One of the diseases that require active engagement of the affected individuals is diabetes [6, 21, 25]. Management of blood sugar levels requires significant alterations to one's lifestyle, with major effects on diet and physical activity. The chronic nature of the disease leads to individuals favoring balance between desired lifestyle and health over adoption of completely risk-free behaviors. And, perhaps most importantly, drastic individual differences demand that those affected rely on individual discovery of patterns and correlations in past experiences as much as on advice from professionals. This renders *reflective analysis of past experiences* one of the most essential skills in diabetes management [19].

Supporting *reflection*, or ones' ability to reach conclusions relying on one's memory or personal experience [4] is one of the most persistent yet elusive goals of computing technologies [8]. Recent research confirms that enhanced access to captured individual records can facilitate both recall and recollection of past events [23]. Consequently, the focus of many emerging health monitoring applications remains on the discovery of capture techniques that allow recording of large volumes of diverse data [2, 9, 18]. However, we argue that reflective thinking requires more than memory support; individuals need to be able to engage with the data, analyze it, and reach certain conclusions from it. In this scenario, richer access to data would undoubtedly benefit professional knowledge workers but might present challenges to the untrained individuals. In this paper we describe our continuing efforts for complimenting capture techniques with mechanisms for engaging individuals in the analysis of the captured health records. In particular, we adopt the view of learning as a social process and focus on *social scaffolding* mechanisms that help novices acquire and develop reflective thinking skills.

In this paper we present MAHI (Mobile Access to Health Information), a health monitoring application for individuals with diabetes that places specific focus on the development of reflective thinking skills through social interaction. MAHI is a distributed mobile application that includes a conventional blood glucose meter, a Java-enabled cell phone, and a Bluetooth adapter, to support communication between the glucose meter and the phone (see Figure 2) Individuals with diabetes use MAHI to record their blood sugar levels and diabetes-related challenges, such as questions, problems, or activities of interest using phone's image and audio capture; simple asynchronous communication mechanisms allow individuals to share their records with a diabetes educator through a website and engage in a discussion over the records. A theme that further develops later in this paper is that MAHI is particularly well suited for individuals newly diagnosed with diabetes who are forced with the challenge of examining and altering elements of their daily routines.

While the general usefulness of health monitoring applications is undoubted, many of the evaluation studies carried on so far focused almost exclusively on qualitative assessments and participant self-reports [10, 20]. Consequently, one of our goals was to introduce more objective measures of MAHI benefits. We deployed MAHI with 25 newly diagnosed individuals with diabetes (type 1 and type 2) as part of their 4-week diabetes education program. During this challenging time, individuals acquire basic knowledge of diabetes and develop management skills. Most importantly, during this time individuals learn to reflect on their unique individual experiences. We expected MAHI to contribute to individuals' understanding of the disease, their perception of their role in managing it, and their achievement of the actual management goals.

The results of the study demonstrate that MAHI contributed to the changes in participants' attitudes and behaviors achieved as a result of engagement with the diabetes education. Specifically MAHI helped individuals reach their management goals, such as change in diet. More importantly, however, usage of MAHI had a significant impact on individuals' sense of control over their disease and their perceived role in the management. Participants using MAHI were more likely to report internal locus of control [24] than those in the control group. This suggests that individuals with MAHI experience were more likely to continue active engagement in care and sustain the positive changes achieved as a result of the education.

Initial analysis of MAHI usage patterns and the qualitative interviews with study participants and educators indicated that in the most successful cases the educator was able to coach learners through reflective thinking by demonstrating reflective analysis of individuals' records. This coaching allowed learners to observe and imitate the educator and gradually engage in independent analysis. These observations allow us to conclude that access to individual histories combined with simple data sharing and communication mechanisms can serve as social scaffolding for the development of individual reflection, and thus have positive effects on diabetes management.

In the rest of this paper we frame this work by discussing recent trends in life-logging and health monitoring applications. We then present MAHI's design, discuss the deployment study and details the quantitative analysis of the study results. We close by outlining our vision for future analysis and draw implications for the design of health monitoring applications.

RELATED WORK

The idea of augmenting human memory with digitally captured records or "logs" can be traced back at least to the 40s [8]. The general vision, still influential for the family of applications known as *capture and access* [1] or *life-logging* [23] is that technology allows humans to capture relevant experiences and review them at a later date. While the general vision remains relevant, the technologies for both capture of records and access to them transformed significantly allowing more data to be captured automatically and striving for access anytime anywhere. On the capture side, Sellen distinguishes between wearables, portables or augmented environments [23]. From the access perspective, one of the main promises is that these technologies will augment individuals' memory of their own past. In fact, studies show that such applications do have potential for augmenting individuals' recollection and recognition of events in the recent past.

A somewhat different class of applications specifically focuses on monitoring of health and health-related information. Much of the work in this area targets the development of innovative mechanisms for identification and capture of specific activities relevant to one's health. For example, Amft et al. [2] use acoustic analysis of chewing sounds for dietary monitoring. Using a small microphone inserted into an individual's ear, the researchers are able to reliably distinguish chewing sounds from other acoustic effects, such as speech. Chang et al [9] use an augmented environment approach enriching a dining table surface with RFID sensors and weight sensors to monitor what and how much of the foods available on the table each individual consumes in the course of the meal. The feasibility studies of the augmented table surfaces have shown 80% accuracy, comparable to that of the traditional dietary assessment methods.

On the access side, there are examples of new applications that use collected health-related data to influence individuals' behavior by using emotional or social mechanisms. For example, Fish'n'Steps [17] attempts to promote higher levels of physical activities by mapping one's steps measured with a pedometer to the development of an animated character, a fish in a fish tank. Another application in this family [11], uses social communication between friends to achieve the same goal – promote increased physical activity.

At the same time, examples of applications that focus on promoting reflection for lay individuals managing chronic diseases are not easy to come by. Much of the work in the novel capture techniques focuses almost entirely on the sensing side, with less attention to the access part of the equation. At the other side of the spectrum, applications that strive for behavior change tend to focus on the actual behaviors or readiness to change them, rather than on analytical and reflective skills of the individuals. At the same time, reflective analysis of past experiences is one of the most critical skills in the management of such diseases as diabetes [19].

There are, however, numerous examples of designs that promote decision making for experienced knowledge workers [for example, 5]. These applications focus on presentation of collected data that improves experts' ability to make select optimal decision from a number of alternatives.

In the design of MAHI we attempted to fill what we saw as a gap and focus specifically on lay individuals' ability to learn from health-related personal records. In particular, we focused on social scaffolding that can help novices in diabetes management develop reflective thinking skills.

MAHI DESIGN

MAHI is a distributed mobile application that includes a conventional blood glucose meter, such as LifeScan's OneTouch Ultra [28], a Java-enabled cell phone, such as Nokia N80 [29] and a Bluetooth adapter, such as a modified and custom-programmed Brainboxes BL-819 RS232 Bluetooth Converter [30] to support communication between the glucose meter and the phone (see Figure 2) MAHI was designed to function in authentic real world situations. Consequently, our design focus was on mobility, portability, size, robustness and power consumption. Specifically, we selected a Java-enabled mobile phone to ensure easy access throughout the day. In addition, we took special measures to ensure mobility and durability of the Bluetooth connection. We modified and reprogrammed the Bluetooth converter to be powered by lithium batteries, ensuring uninterrupted functioning for one week. To protect the Bluetooth board and ensure its durability during the deployment, we built a custom plastic case for the Bluetooth converter using a 3-D printer.

Below we describe some of MAHI design choices and theoretical rationale behind them.

Figure 1: Mobile components of MAHI

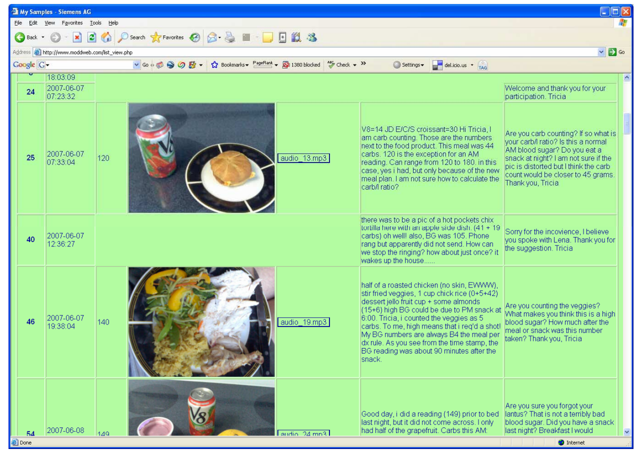

Figure 2: MAHI website (screenshot of the actual site usage). The columns include: 1) record number, 2) date and time of capture, 3) blood glucose value, 4) picture(s), 5) audio, 6) participant's comments posted directly to the website, 7) educator's comments posted directly to the website.

Adopting a sensemaking framework

Much of the work in supporting decision-making for analysts tends to be informed by research in decision-making [22] that has a clearly defined normative character and presupposes an existence of an "optimal" decision in majority of situations. Studies of decision making approaches tend to focus on deviations from these golden standards.

In our attempts to enhance lay individuals' reflective thinking about their diabetes, we found decision-making framework to be somewhat constraining. Studies of organization behavior suggested an alternative approach favoring *sensemaking* over decision-making. Rather than focusing on deviations from "golden standards" of good decisions, proponents of sensemaking focus on individuals' ability to make sense of challenging real world situations. "Sensemaking is not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data, and is resilient in the face of criticism." [27]. In accordance with sensemaking our goals in designing MAHI are to help individuals make progress in understanding their disease by providing them with enhanced access to relevant records from the past and helping them shape their reflective thinking skills. Furthermore, MAHI deployment studies are designed to avoid comparisons with "optimal" decisions and focusing on the nature of insights that participants gained during the studies.

Breakdowns of routines as a focus of investigations

Reliance on sensemaking paradigm suggested a particular approach to the design of the capture mechanisms for MAHI. Rather than helping individuals capture pre-defined activities, such as meals, exercise or medication, MAHI utilizes a more flexible design to allow capturing anything that disrupts regular activities and presents a *breakdown* in a routine.

In the language of sensemaking, breakdowns happen when individuals experience "a fleeting sense of meaning of situations" [27]. When confronted with an unexpected situation, individuals notice its salient properties and articulate them in language. This realization and articulation of breakdowns serves as a trigger for reflection when individuals become open to analytical engagement with the situation.

The notion of breakdowns is particularly relevant for individuals with diabetes. In the weeks and months following the diagnosis, individuals are forced to "problematize" many of their established routines, such as shopping and cooking, participating in social events, and attitudes toward stress or exercise. With time, new behaviors become settled as new routines, which no longer cause breakdowns. However, the time of transition between one set of routines to another presents considerable challenges to the individuals and opportunities for technological support.

For the purposes of our research we define routine breakdowns as moments in individuals' daily lives when their diabetes becomes the center of their conscious thought and attention. Examples of such breakdowns could be situations when individuals need to make dietary choices (buying groceries, or ordering in a restaurant), or wonder about their health indicators (while looking at the recent blood sugar readings). MAHI provides two ways of capturing such moments: through free-form capture of individuals' accounts of their experiences and through capture of their compensation strategies, such as usage of a glucose meter.

Consequently, MAHI can be used in two modes, as a diary and as an experience sampling tool. As a diary, MAHI allows individuals to record voice notes and photographs (using a cell phone camera) through a custom user interface. As an experience sampling tool, MAHI initiates recording sessions when individuals use their blood glucose meter. At that time, MAHI establishes a Bluetooth connection between the meter and the phone, allowing the phone to query the meter for the recently captured readings and initiate an experience sampling session with a short ring. During the session, individuals are asked to record the reasons for using the glucose meter, and the context of usage by capturing voice notes and photographs. The captured records are packaged by MAHI and transferred to a MySQL database hosted on a secure dedicated web-server.

Social nature of learning

One of the most important aspects of MAHI design that we believe distinguishes it from many health monitoring applications is its focus on mechanisms for sharing captured records and engaging in a discussion. At the same time, MAHI is different from the many commercially available health monitoring technologies in that it does not place the clinical professional in charge of generating opinions and choices. Instead, MAHI allocates them an advisory role in facilitating individuals' sensemaking, but not replacing it.

The strong motivation for this position came from our previous work designing and deploying ubiquitous computing applications that facilitate individuals' reflection on their past activities [19]. The deployment study of our previous application, CHAP [19], was designed to allow the researchers to observe participants engaged in reflection over records collected during the day (activities, blood sugar values captured every 5 minutes). Most of such end-of-day interviews with the participants followed a relatively stable pattern: when presented with the data collected during the day, the individuals engaged in the reflective monologue, which concluded with the inevitable question directed to the present researcher: "Can this be true?" The individual discovery did not seem to produce reliable knowledge for the participants. Instead, it produced hypotheses that required social validation or confirmation. On one hand, this created a rather awkward situation for the researchers who were able to provide neither the relevant personal experience, nor the expert medical opinion. On the other hand, it brought to the researchers' attention the need for supporting social structures necessary for individual knowledge formation.

In the current version of MAHI, we focused on supporting communication between individuals with diabetes and their diabetes educators. A web-based application using PHP offers access to dynamic, password-protected websites where individuals and their educators can review captured records, and engage in a dialog by providing comments, feedback and additional questions in a message board style (Figure 2). The decision to share records automatically rather than by individuals' choice would not be appropriate for peer-level exchange but is justifiable in context of high trust in patient-educator communication.

STUDYING REFLECTION

Controlled laboratory experiments play a dominant role in the decision-making tradition. In contrast, sensemaking studies tend to rely on qualitative techniques inspired by ethnography. In MAHI deployment studies, we adopted an integrated approach that embraced the complexity and unpredictability of real world environments and situations while maintaining a certain level of theory building rigor regarding changes in people's attitude and behavior.

In our previous work [19] we adopted Technology Probes as a model for our explorations. Technology Probes as research methodology serve dual purpose [12, 14]; on one hand they support certain activities and behaviors, on the other hand they become disruptive research tools that allow investigation of these activities. This dual nature resonates with a research methodology popular in the Learning Sciences domain, known as Design-Based Research (DBR)

[3]. Proponents of DBR see their goals as both development of new theories of learning and development of practical tools that facilitate learning in very concrete educational settings. To accomplish this, DBR adopted four important research practices:

- Commitment to understanding of education in real world settings
- Flexible approach to study design that allows for alterations to the variables in the course of the study
- Embracing an active role for researchers participating in the educational process
- Favoring a generative approach over disconfirmation of pre-selected hypotheses

In our deployment studies we borrow from both Technology Probes and DBR approaches in that:

- MAHI serves as both a research tool to investigate individuals' reflective thinking about diabetes, and an intervention that facilitates this reflective thinking
- MAHI deployment studies are conducted in authentic situations with minimal intrusion from the researchers; at the same time, the researchers take on a proactive role in the education process (one of the investigators taught the diabetes education classes observed during the study)
- While we approached our studies with an initial set of hypotheses, our research team favors generative approach to theory development. Consequently, much of the analysis focused on qualitative aspects of the study, such as content analysis of the nature of conversations captured on the website and qualitative interviews with study participants. However, in this paper we focus on the quantitative measures of MAHI effectiveness.

MAHI Deployment Study

The deployment study was conducted in collaboration with the St. Clare's Hospital Diabetes Education Center in Dover, NJ. The education program includes a number of personalized sessions with certified nurses and certified diabetes educators and registered dieticians to establish personal care goals, and weekly diabetes education classes, in which the students are familiarized with the physiological nature of the disease and different aspects of care. The two recruitment criteria included age (below 65) and experience owning and using a cell phone (over 1 year) to minimize confounds due to cell phone usability.

The research team recruited 49 individuals from the newly enrolled students of the center as part of their educational program. The study used a between-subjects design. Half of the participants (25) were assigned to the experimental group, provided with mobile phones, glucose meters and Bluetooth adapters and were asked to use MAHI during the four weeks of the program. Another half (24) was assigned to a control group and received all of the benefits of the diabetes education but did not use MAHI.

Prior to their first class, the individuals were invited for a 45 to 60 minute individual interview and reimbursed $20. During this time, the researchers 1) discussed the study in detail and obtain an informed consent; 2) asked the participants to fill out the necessary questionnaires, discussed below; 3) the individuals in the experimental group received MAHI and the corresponding training.

Once the classes started, the individuals in the experimental group were expected to use MAHI independently, with no additional meetings with the research team beyond their attendance of the classes. During the class time, their glucose meters with Bluetooth attachment were collected for battery exchange. At the same time, the individuals were given an opportunity to ask questions, and discuss their experience with the researchers. The researchers attended and audio recorded all the classes that had recruited participants. Once the classes were completed, the individuals were invited for another qualitative interview and reimbursed $30.

Research Questions

In spirit of the Design-Based Research, we approached the study with a set of initial hypotheses and measures of MAHI effectiveness in enhancing individuals' diabetes understanding and management. Our main hypothesis was that enhanced personal reflection and opportunity for social validation will have a positive impact on the following three aspects:

Emotional state: In particular, we focused on an individual's sense of control over their health and disease as well as overall quality of life. To measure the impact on the emotional state we utilized the standard Health Locus of Control [24] and Diabetes Quality of Life [7] questionnaires. Our expectation was that MAHI will encourage individuals to adopt internal locus of control (viewing self in charge of one's health rather than placing responsibility on powerful others or chance) more than attending diabetes education classes by themselves. In addition, we expected MAHI to improve individuals' perceived quality of life.

Analytical state: In particular, we evaluated the individuals' understanding of diabetes. The measurement tool, diabetes understanding test was designed by the Diabetes Education Center and routinely deployed to assess the quality of the education. We expected that individuals in the experimental group will demonstrate higher score on the test than those in the control group.

Behavior: In particular, we assessed individuals' achievement of their management goals, such as change in diet and improvements of actual diabetes management practices including number of meals per day, frequency of exercise per week and frequency of blood sugar monitoring per week. All of these indicators are assessed by the personnel of the center prior to students' enrollment in the classes and upon completion of the classes. Again, we expected individuals in the experimental group to demonstrate higher level of reported goal achievement and behavior change than those in the control group.

Study Results

In this section we focus on the results of the four quantitative measurements discussed above.

General Demographics

A series of two-tailed t-tests performed on general demographics did not reveal significant differences between the two study groups in any of the following: age, gender, race, educational level, diabetes type or severity (measured by the results of the standard diabetes test, Hemoglobin A1C). These results indicated the success of the random assignment of participants into the two conditions.

Overall User Feedback

The overall usage rates of the application and the qualitative interviews with study participants indicated that MAHI became an important part of the diabetes learning for many of them. Close to half of all participants in the experimental group (10 out of 25) demonstrated high levels of engagement with MAHI and reported high levels of satisfaction with it, illustrated in the following message left by one of study participants on the website:

> *"Thank you for all of your help and advice - having access to you in almost "real-time" has been very helpful to me, and you have answered many of my questions and provided very meaningful assistance. I feel much more comfortable in dealing with the day-to-day issues of my diabetes, knowing what to expect, and most importantly knowing not to obsess over each and every individual bg reading. I hope that at some point every new diabetes patient will have access to this type of service."*

Different participants valued different aspects of the application. For some the continuous link with the educator was of the utmost importance:

> *"I feel like a fledgling pushed out of the nest now. It was so great to know that someone is watching over me; now I am on my own."*

Others reported benefiting most from having access to the records themselves:

> *"Somehow every time I looked at the images of my meals I saw something different than what I saw when I was cooking them. I always thought I was making great choices and then I would look at the picture and think – wait a second…"*

MAHI General Usage Patterns

With rare exceptions, the participants demonstrated high levels of engagement with MAHI collecting over 1000 records during the 5 months of the study. The total and average numbers of records and their components are presented in Table 1. The drop out rate was minimal: only one participant did not complete the study due to health complications (surgery); one other participant completed the study but was not available for the exit interview and post-study questionnaires.

	Sum	Average
Samples	1089	43.56
Glucose	564	22.56
Images	308	12.32
Images of glucose meter reading	67	2.68
Audio	540	21.6
Web postings	419	16.76
Provider's postings	644	25.76

Table 1: MAHI usage patterns

The twenty five individuals enrolled in the experimental condition demonstrated high variability in their usage of MAHI, with the numbers of records collected ranging from 2 to 135 (Figure 3, Table 2).

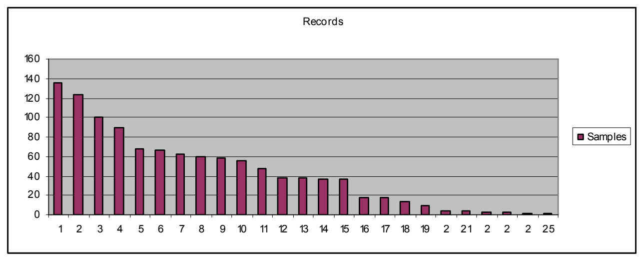

Figure 3: Number of records captured with MAHI

# of samples	0-20	21-50	51-135
# of participants	9	6	10

Table 2: Participant activity levels

The initial analysis of participant interviews allowed us to identify a number of reasons for the lack of engagement with MAHI, which included the following:

Technophobia and general technology reservations: many participants in this category experienced difficulties with either using the phone or the website. Some lost access to the internet during the study and could no longer take advantage of the website (2 participants). Others were generally uncomfortable using phone menus (3). Yet others were intimidated by the expensive-looking phone and were afraid to break it (2).

> *"I was taught when I was a kid: if it's not yours, don't touch it. I am not really good with technology, and I always break things, so I was really afraid I would break something."*

In general, usability issues with Nokia N80 phones were the main source of technical difficulties for the study participants. Most participants actively used phones and their media capture features, however, small size and high sensitivity of buttons made navigation challenging even for younger participants. While we continue to share the enthusiasm for mobile phones as a platform for pervasive healthcare applications common for the research community, these findings warned us of the possible tension between complex models of phones, such as N80 and users' desire for the simplicity of interaction.

Lack of time, interruptions: during the exit interviews several participants revealed that they were not able to take advantage of the application as much as they had hoped due to unexpected interruptions to their participation. These included health complications, family problems, work travel or job transitions (3).

But perhaps the most common reason for low participation was a visibly *low level of personal interest* in the captured records or their analysis (5 participants). Often, these participants dutifully recorded their blood sugar levels, and added comments and explanations. However, they never attempted to engage with the records, either ignoring the website completely, or only visiting it a few times out of curiosity. The post-study interviews revealed an intriguing similarity in these participants' attitudes to health and healthcare, expressed in the following quote:

> *"My job is to collect the records for you and for my doctor; it is his job to tell me what these records mean and what I should do about it."*

This observation led us to question the potential correlation between individuals' pre-study locus of control and their level of engagement with MAHI. We report on these findings below.

Emotional State

Within this category, we used two standard questionnaires to measure participants Health Locus of Control (HLOC) [24], and their Diabetes Quality of Life (DQL) [7].

The HLOC questionnaire consists of 15 questions that place individuals in one of the three categories: those with internal locus of control (Internal), those with external locus of control who place responsibility on powerful others (External Others) and those with external locus of control who are likely to attribute things to chance (External Chance). Those with equal scores in multiple categories are placed into the fourth, Neutral group. The main question in our study was whether MAHI could compel individuals to realize and appreciate their own role in diabetes management, and adopt an internal locus of control. Consequently we collapsed across the two external locus categories and looked for the differences between internal and combined external locus of control. The results confirmed our hypothesis: **significantly higher number of individuals switched to the internal locus of control in the experimental group (X_1^2=4.17, p<0.05).** In contrast, fewer individuals in the control group reported an internal locus of control at the end of the study; than at the onset; however this difference was not significant. The overall results of the questionnaire are presented in Table 3.

	Control (pre)	Control (post)	MAHI (pre)	MAHI (post)
1	15	13	15	20
2	2	4	4	1
3	5	3	6	4
4	2	1	0	0

Table 3: Health Locus of Control (distribution of participants per loci: 1-Internal, 2-External, Powerful others, 3-External, Chance, 4-Neutral)

An additional question we had in regards to HLOC was whether internal locus of control would lead to higher level of engagement with MAHI for the participants in the experimental group. We found a weak correlation between HLOC and the number of records individuals made using MAHI ($r_{Pearson}$=-0.22, p=0.15, the negative sign is due to the directionality of the HLOC: "1" corresponds to the internal locus) in the anticipated direction (internal locus of control leads to higher participation), which, however, remained not significant.

The DQL questionnaire consists of 15 questions and returns a numeric value. Analysis of DQL results [by Analysis of Variance (ANOVA)] for both groups pre and post study indicated that there was an overall improvement in quality of life after completing the classes, F(1,43)=253.25, p<0.0001). However, there were no significant differences between the groups, F(1,43)=1.57, *n.s*. The results of the questionnaire are presented in Table 4.

Group	Pre-study	Post-study
Experimental	33.261	29.913
Control	35.5	32.136
Total	34.356	31.000

Table 4: Diabetes Quality of Life (lower score corresponds to higher quality of life)

Analytical State

The Diabetes Understanding Questionnaire was used to assess individuals' understanding of their disease before and after the study. The questionnaire consists of statements about diabetes that needed to be evaluated as true or false. Points are taken out from the final score for each incorrect answer. As with the DQL, we found a significant improvement in the participants scores across groups (F(1,35)=24.98, p<<0.0001) However, there were no significant differences between the groups (F<1). The results of the questionnaire are presented in Table 5.

Group	Pre-study	Post-study
Experimental	-2.10	-1.15
Control	-2.24	-1.24
Total	-2.16	-1.19

Table 5: Diabetes Understanding Questionnaire

Behavior

Finally, in the behavior category we paid particular attention to the achievement of management goals, such as change in diet. In addition we looked separately at three different indicators: 1) individuals' meal patterns (from 1: the least desirable "no stable pattern" to 6: the most desirable "3 meals, 3 snacks") 2) monitoring frequency per week (with more frequent testing deemed more desirable) and 3) exercise frequency per week (with a higher number deemed more desirable). All of these measures were based on participants' self-reports obtained during the pre-study and post-study visits. The results of these assessments are presented in Tables 6 and 7.

Group	MAHI	Control
Diet goals	1.16	1.59

Table 6: Diet goals achievement results (1- achieved, 2 – did not achieved)

	Group	Pre-study	Post-study
Meals	Experimental	2.08	3.56
	Control	1.55	4.00
	Total	1.83	3.77
Exercise	Experimental	1	3.08
	Control	1.14	2.86
	Total	1.06	2.98
Monitoring	Experimental	6.28	15.84
	Control	5.68	15.41
	Total	6.00	15.64

Table 7: Reported behavior changes

The diet goal achievement results confirmed our hypothesis: **individuals in the experimental group reported significantly higher level of diet goal achievement than those in the control group ($t_{\text{1-tailed}}$(45)=3.36, p<0.001)**. In all of the remaining behavioral categories, we found a significant improvement for both study groups (F(1,45)=44.38, p<<0.0001; exercise: F(1,45)=42.36, p<<0.0001; monitoring: F(1,45)=88.14, p<0.0001). However, none of these categories returned significant differences between the experimental and control groups.

Discussion

One of the goals of MAHI deployment studies was to find objective measures for assessing the benefits of the application. We anticipated use of MAHI to lead to more significant changes along 3 different dimensions: emotional state, analytical state and actual behavior than participation in diabetes education alone.

The findings indicated that both groups achieved significant improvements along all three anticipated dimensions. Especially drastic were the changes in the reported diabetes management with many individuals adopting healthier diets (switching from "no pattern" to more desirable categories), increasing exercise frequency (often from none to several times per week) and monitoring frequency (often from none to over 14 times per week). These results once again confirm the general benefit of diabetes education as a powerful intervention for individuals with diabetes.

In addition we found that usage of MAHI significantly contributed to individuals' improvement along these dimensions, specifically in those categories concerned with personal goals. For example, MAHI users were able to achieve their diet goals more so than individuals in the control group.

However, and more importantly, usage of MAHI led to significant changes in individuals' perception of their role in diabetes management. As we expected, the ability to monitor one's experiences, formulate and review questions and discuss the records and questions with the diabetes educator resulted in more individuals adopting internal locus of control. Historically, patients have been more than willing to give up any and all responsibility for their treatment to what Wallston and Wallston identified as the "external locus of control: powerful others" in their pioneering applications of the Health Locus of Control [24]. Later studies in diabetes have shown that understanding the patient's Health Locus of Control can be a key component to improving the patient's self-management skills in diabetes. Ultimately, the patient's health belief structure can influence adherence to self-care instructions and metabolic control of diabetes [26]. The shift towards internal locus of control indicates that those participants who used MAHI while attending the diabetes classes are more likely to continue active engagement in diabetes care compared to those who were not exposed to the application. To further validate this finding, in our future work we plan to contact study participants and re-evaluate the stability of the achieved changes 3 months and 6 months after completing the study.

However, we also found that the effect of MAHI was not as strong as we expected, particularly in such categories as diabetes quality of life, diabetes understanding, and in the actual reported behaviors. While most of these categories displayed trends in the anticipated direction, these trends were not significant. There are several possible reasons for this lack of statistical significance in some of the result categories. For example, the diabetes understanding standard assessment tool evaluates a person's generic understanding of diabetes (i.e. book knowledge). This assessment tool is not sensitive to the kinds of increased personal understanding that is more typical of the insights people gained using MAHI. In addition, in such categories as actual reported diet, exercise frequency, and monitoring frequency, the magnitude of change achieved by all the participants irrespective of their engagement with MAHI may have prevented us from seeing the influence of MAHI itself. As mentioned earlier, many of the participants shifted from no management (no meal pattern, no exercise and no monitoring) to adopting stable diets and regular exercise and testing blood sugar at least twice a day. Perhaps the effect of MAHI could have been more apparent if it was deployed after the individuals completed their education. However, qualitative interviews with study participants and educators indicated that for many individuals enrollment in classes leads to the sudden explosion of questions and concerns regarding diabetes; providing the tools that support individual reflection and discovery during that time might have unique benefits and help individuals cope with the new burden of the disease.

GENERAL DISCUSSION AND FUTURE WORK

The focus of our investigations is on computing technologies that help individuals with diabetes engage in reflective analysis of past experiences in order to refine future choices. Our current prototype, MAHI helps individuals capture rich media records indicating past actions and blood sugar levels and discuss these records with their diabetes educators. The deployment study of MAHI resulted in a relatively high acceptance rate; almost half of all recruited participants actively engaged with the application and reported high satisfaction rates. More objectively, MAHI significantly contributed to individuals' achievement of their management goals (diet). Even more importantly, it helped its users realize their role in diabetes management and adopt an internal locus of control. Research shows that internal locus of control is more likely to result in continuous engagement in self-care and lead to more sustained behavior changes [26].

Encouraged by such positive findings, our aim for future analysis is to explicate particular MAHI features that contributed to these results. Our immediate next step is to continue a thorough analysis of MAHI usage records. Specifically we are interested in whether there are any particular usage patterns that can hint at what made MAHI beneficial for the users and how users engaged with the application. We intend to analyze the nature of the discussions on MAHI website and recorded class discussions for the potential changes in the discourse about diabetes.

Our initial review of qualitative interviews with the study participants provide hints as to the answers we seek. The most salient of these is the importance of combining data capture with the possibility to discuss the records with an educator. We review both of these in turn.

Sharing Data

For many of the participants, engaging with MAHI presented a certain challenge: they were not sure what to capture, how often and what questions to ask. However, in many such cases, after a short period of time, there emerged a particular pattern: either the individuals or the educator would identify a problem based on the captured records (for example, unusually high fasting morning blood glucose reading). The educator would often continue the exchange by asking probing questions about possible reasons for the problem or advancing plausible explanations, framed as hypotheses, inviting the participant to join in the analysis. In this way the educator was able to coach the participants through reflective analysis, demonstrating it by example and providing guidance on the way. For many participants these coaching sessions became the most valuable experiences of the study:

> *"Half the time I didn't even answer her questions. But I knew that those were questions for me; this is how I should be thinking. Now I can look at these records and I know what to look for and how to look for it."*

Access to Data

The observations above lead to a question of whether MAHI could have had the same effect without the complexity of custom hardware and mobile application for automated data capture. Could a simpler message board allow for the same exchange and experience? We hope to explore this question further in our future analysis; reviewing educator-participant dialogs will demonstrate the role of the captured data in the conversations. However, interviews indicate that sharing access to data was essential for both the educator and the participants. For example, it presented visible triggers (problems in the records) for initiating conversations. While all individuals enrolled in the classes are continuously encouraged to contact the educators, those contacts are rare in either direction. At the same time, the data allowed the educator to shape the questions and the coaching in way meaningful to the participant:

> *"Otherwise, I would just have to ask the same questions of everybody and it is very hard to engage people with generics."*

Designing for long-term adoption

Many of our participants mentioned that such intensive and focused exchange with the educator is most beneficial at the beginning of their engagement with diabetes management. At that time one's management skills and reflective thinking are beginning to take shape and can benefit from feedback and guidance. However, the same intensity can hardly be sustained beyond the initial weeks. After this time, individuals often continue refining their skills by engaging not only with the educator, but also with a community of peers through face-to-face or online support groups.

Our new application, Di-Tag is inspired by the idea of learning through participation in a community. It uses capture techniques similar to MAHI, but augments the educator-participant dialogs with an ability to share experiences with a community of peers. Studies of Di-Tag are currently underway and we hope to report on them in the near future.

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