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Building *MedVenture* – A mobile health application to improve adolescent medication adherence – Using a multidisciplinary approach and academic–industry collaboration

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Abstract

Objective: Mobile health (mHealth) tools are increasingly used to support medication adherence yet few have been designed specifically for the pediatric population. This paper describes the development of a medication adherence application (*MedVenture*) using the integration of patient and healthcare provider input, health behavior theory, and user engagement strategies for adolescents with chronic gastrointestinal disease.

Methods: *MedVenture* was created by a multidisciplinary research team consisting of a gastroenterologist, a social health psychologist, software developers, and digital health researchers. Healthcare providers and adolescent patients were interviewed to identify barriers to medication adherence, explore ways that technologies could best support medication adherence for both patients and providers, and determine user requirements and core design features for a digital health tool. Intervention mapping was used to match themes from qualitative content analysis to known efficacious adherence strategies, according to a conceptual framework based on self-determination theory. Iterative design with review by the research team and two rounds of user testing informed the final prototype.

Results: Three themes were identified from content analysis: 1) lack of routine contributes to nonadherence, 2) adolescents sometimes purposefully forgo medications, and 3) healthcare providers would prefer a tool that promotes patient self-management rather than one that involves patient-provider interaction. These findings, combined with evidence-based adherence and user engagement strategies, resulted in the development of *MedVenture* – a game-based application to improve planning and habit formation.

Conclusions: Academic-industry collaboration incorporating stakeholders can facilitate the development of mobile health tools designed specifically for adolescents with chronic disease.

Keywords

Mobile health, digital health, app, compliance, health behavior theory, gamification

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Introduction

Medication nonadherence is a common problem that results in increased morbidity and mortality[1] as well as places a significant cost burden on healthcare systems.[2] Adolescents with chronic conditions that require long-term maintenance of therapy – such as those with solid-organ transplantation, chronic respiratory conditions, or inflammatory bowel disease – are at increased risk

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for disease complications given high nonadherence rates in the adolescent population.[3,4] Numerous interventions to promote medication adherence have been tried in the past such as education and reminders without sustained improvement.[5] However, recent data suggests that health theory-based interventions and those that focus on planning and habit-formation may be more beneficial.[6–8]

Given the near universal use of mobile phones across all populations including adolescents and young adults,[9,10] phone-based applications to promote and maintain health have become common tools.[11,12] In fact, recent literature has suggested that there is not only ubiquitous access to technology but also an interest in mHealth among adolescents and young adults with chronic disease, including people of diverse racial and ethnic backgrounds.[13–16] There is growing evidence to support the use of technology by adolescents specifically to improve health outcomes. Technology designed for adolescents has the potential to ease the transition to adulthood by empowering adolescents to self-manage their chronic health conditions.[17]

Digital interventions have not only been shown to be feasible and acceptable to adolescents with chronic diseases,[18,19] but have also improved self-management skills in a diverse range of diseases including adolescent sickle cell disease,[20] obesity,[21] mental health disorders,[22] and adult medication adherence.[23] Moreover, a recent systematic review showed that text messaging and mobile health (mHealth) applications ("apps") were effective in improving medication adherence in adolescents with chronic disease as well.[24] While these studies are promising, most apps for medication adherence have relied on reminder systems rather than planning and habit formation.[25] In this paper, we describe the development of a mHealth tool using the integration of health behavior theory, planning and habit formation techniques, and user engagement (including gamification) to promote medication adherence in adolescents with prior liver transplantation.

Methods

Study design

Figure 1 depicts the overall workflow used to create *MedVenture*, a gamified mHealth app designed to support motivation, planning, and adherence to anti-rejection medications for use by adolescents with prior liver transplantation. *MedVenture* was designed by a multidisciplinary research team consisting of 1) a gastroenterologist with experience caring for adolescents with chronic gastrointestinal diseases, 2) a social health psychologist with expertise in behavioral theory, 3) a software development team specializing in incorporating health behavior theory into the design of healthcare-based technology, and 4) the mHealth Impact Laboratory – a team of health services researchers with expertise in designing, building, and testing mHealth technology.

Using an iterative process, the research team created interview guides with both open-ended and focused questions. Semi-structured interviews were used to 1) better understand patient-identified barriers to medication adherence, 2) explore ways that mHealth technologies could best support medication adherence for both patients and providers, and 3) gather user requirements and core design features for a mHealth tool. Using these results, the research team met weekly to refine the specifications of the tool. The tool was then built in an iterative manner using agile development processes and a series of two-week design/build "sprints" over the course of four months. Sprints are commonly used in agile software development[26] and are a set period of time during which specific work has to be completed and made ready for review.

Theoretical framework

Because theory-based mHealth interventions are more effective in improving outcomes,[7] self-determination theory[27] was incorporated into the design of the tool. Self-determination theory (SDT) is a widely accepted set of behavioral mini-theories that define how social environments can support or limit motivation and self-regulation of human behavior. According to SDT's Basic Psychological Needs Theory, humans have three basic psychological needs: autonomy, competence, and relatedness. Autonomy is a sense of being in control of one's behaviors and goals, competence refers to a mastery of skills and required tasks, and relatedness is the feeling of being connected to others. Social and environmental support for these three psychological needs (e.g. providing choice as a way to support autonomy needs) has been shown to promote more self-determined motivation for a wide range of human behaviors, including health behaviors, which then promotes more consistent adherence and physical and psychological health.[28] Furthermore, according to SDT's Organismic Integration Theory, the degree to which a behavior is *internalized* (i.e. aligned with one's self-identity and values, beliefs, goal systems) also promotes more self-determined motivation. Mobile health applications have been shown to be an effective tool for integration of SDT concepts into digitally delivered interventions to promote health behavior change.[29] For example, a mHealth tool that allows users to make their own individualized plans for when and how to take their medicines may provide autonomy support. Text message reminders or alarms can support

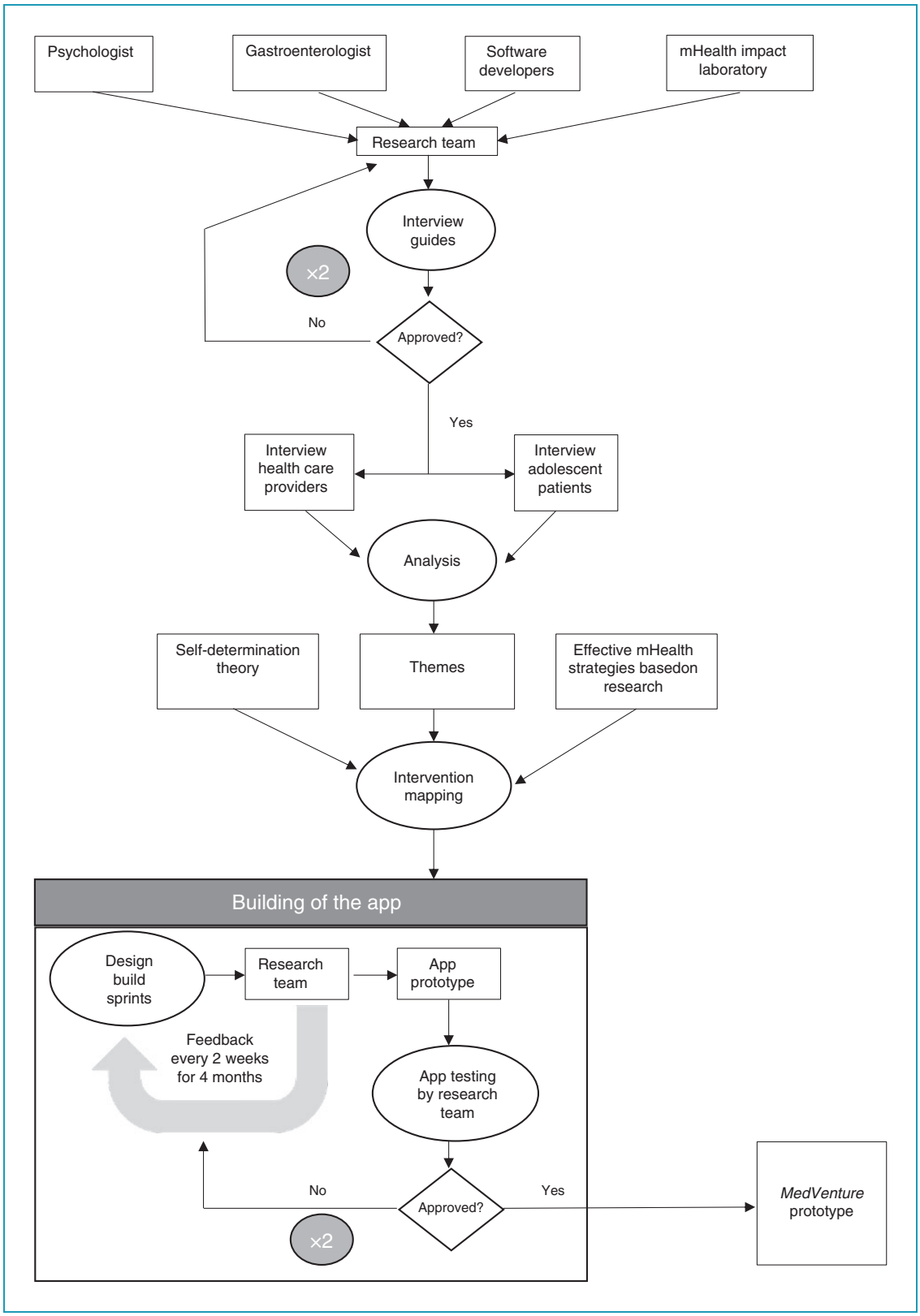

Figure 1. Overview of the methodological design used to build *MedVenture* – a mobile health application to improve medication adherence in adolescents with chronic disease.

competency in medication-taking. Feeling like one is not alone in their struggle, whether through interactions with peers, healthcare providers, or through interactions with the mHealth tool itself can provide a sense of relatedness. For this study, autonomy, competence, and relatedness support and self-identity were operationalized in *MedVenture* in a variety of ways, as shown in the intervention map[30] (Figure 2).

Recruitment and participant characteristics

Two types of end-users were identified: patients and healthcare providers. The profile of target end-users to be engaged in development was based upon characteristics of both individuals expected to benefit clinically from use of the tool and those who are ideal research participants (i.e. will provide the best feedback).[31] Inclusion criteria for healthcare providers were 1) currently employed as a physician, advanced practice provider, or registered nurse, 2) working with transplant recipients for greater than one year, and 3) being active users of Android or iOS smartphones. Inclusion criteria for patients were 1) ages between 13 and 29 years old, 2) history of liver transplantation, 3) currently on immunosuppressive medications, and 4) active users of Android or iOS smartphones. Providers and staff of the Children's Hospital Colorado Transplant Program were asked to nominate and invite patients and healthcare providers that they believed fit this description. Patients were recruited by the gastroenterologist on the research team or members of the mHealth Impact Laboratory during either regularly-scheduled clinic visits or via phone. Participants were paid $20 for being in the study. Consent and assent (when applicable) were obtained from all participants. The Colorado Multiple Institutional Review Board approved this study.

Interviews and analysis

Interviews were conducted in-person or over-the-phone in a private room of the hospital or hospital-associated

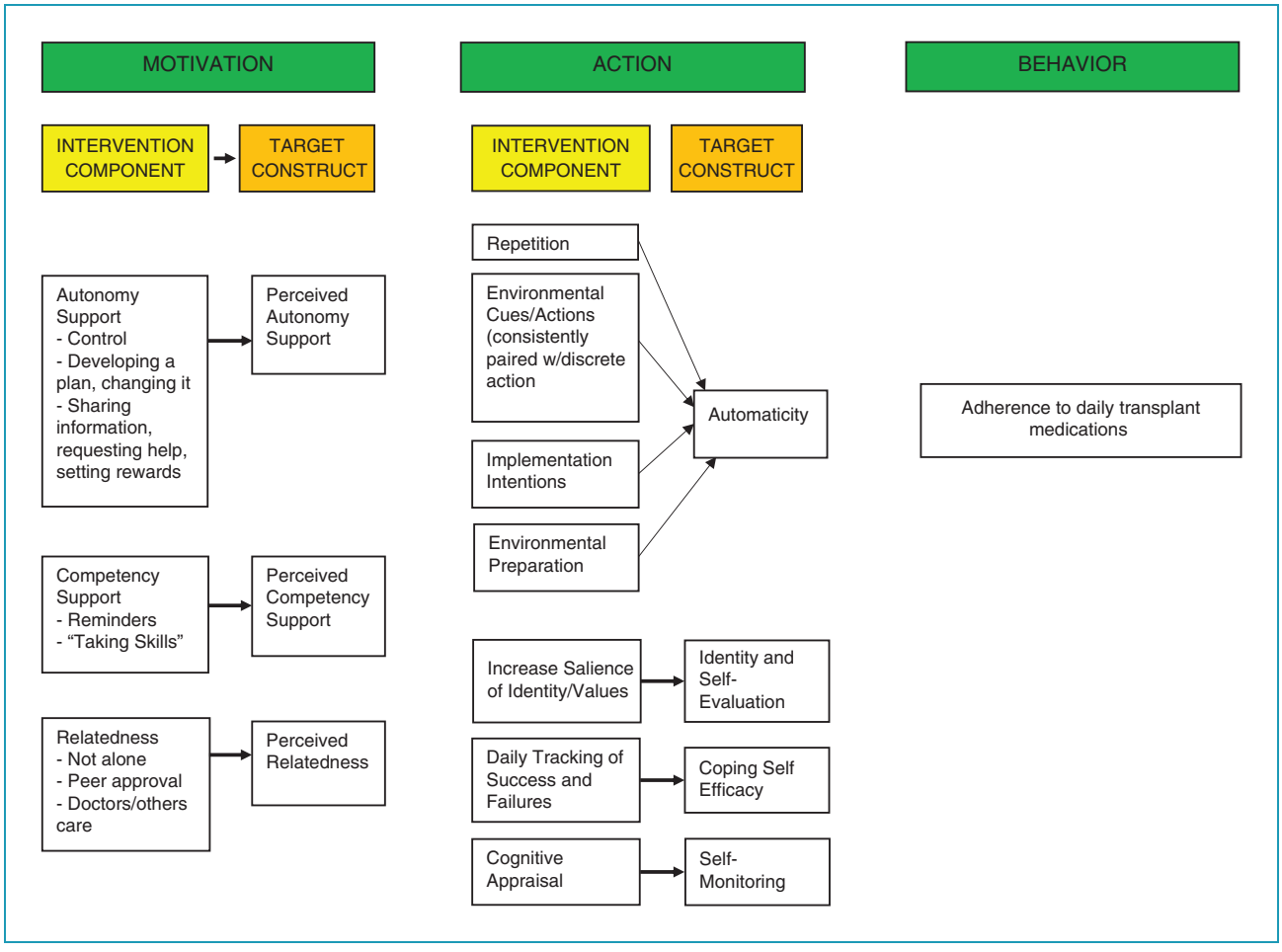

Figure 2. Components of self-determination theory (autonomy, competence, and relatedness) were integrated with other known efficacious adherence strategies to help guide the development of *MedVenture*.

administrative building. Audio-recordings were made of each interview, de-identified, and transcribed verbatim into a text file. Two members of the research team trained in qualitative methods each separately read and re-read the text data. Using content analysis, they created initial coding categories, discussed areas of disagreement, and adjusted the coding scheme until agreement was reached. The process was repeated until the codes were represented under larger themes, or repeated concepts.

mHealth tool creation

The themes of the interviews were presented to the larger researcher team. Intervention mapping[30] was used to integrate 1) the themes identified by the interviews, 2) known efficacious medication adherence strategies, and 3) self-determination theory. This resulted in a consensus agreement on important components of the mHealth tool. The tool was then created in a series of two-week design and build sprints and incorporated meetings and demonstrations during each sprint. Feedback from the prior sprint was used to modify the tool in real-time. Detailed review of the content of the tool was performed by the research team throughout the sprint process. After the initial prototype was created, each member of the research team tested the tool individually and then met as a group to provide feedback to developers. The prototype was then modified and underwent an additional round of individual testing, group feedback, and revision.

Results

A total of four liver transplant recipients and four healthcare providers participated in the interviews. Of the patient subjects, three were male and one was a female. Ages ranged from 12 to 18 years of age. Of the healthcare providers, three were clinicians and one was a nurse specializing in the outpatient care of transplant recipients. Analysis of the interviews generated three overarching themes.

Themes

Lack of routine. Both types of subjects (patients and providers) emphasized that the majority of adolescents were well-meaning and wanted to take their medicines, however they simply forgot to take them. The adolescent subjects often reported that their day-to-day lives were different depending on the day of the week and this made it difficult to find a consistent time to take their medications. On school days, they woke up early but on the weekends, they woke up later. Some adolescents worked part time, some were involved in sports, and some traveled. When asked to describe a typical day, one subject stated, "My days are like—they're not always—I don't have regular days because my days are—one day there's this stuff going on, another day there's this stuff going on. There's not really a set day where things are just a normal day. Everything changes every day." This change in routine and its effect on medication adherence is described by another subject:

> *If I'm at work and I get really busy at work, I can forget. If I have a lot of stuff going on, like just a lot of different things that I have to do, I can forget. If we're gonna go somewhere and I sometimes can forget to take my meds with me, which makes it difficult to get meds on time... Today is probably gonna be a good example. I had school this morning, and then I have to come here. Then, I have an award thing right after this that I have to go to, and then dinner to eat. I could potentially forget my medication at home, and then end up not taking it until later.*

Providers also discussed this lack of routine as a barrier. Many providers used the word "chaos" to describe the home life of their patients. One provider said "but families who are in a little bit more chaos, or there's not a lot of structure and whatnot, I can certainly see where that plays into medication adherence." When speaking about barriers to adherence, another provider reported that "if it's pretty chaotic in the household, it's gonna be harder." A third experienced provider described it as "disorganization," stating "I think there's some moderate amount of chaos in their life, so disorganization. I think disorganization is really hard if you have a complex medical regimen. Trying to stay organized about, oh, yeah, I gotta take my meds twice a day. If you can't remember to do that, can't remember to get your meds, don't have a system. Disorganization is there, and I think general chaos in families does that or chaos in their social life does that."

Limiting the role of the clinician. In discussion with physicians who care for liver transplant recipients, most reported that while they think medication adherence is important, they did not want information regarding their patient's medication taking. One physician reported "Every day, on an hourly basis, my inbox fills with lab results and drug therapy results and imaging results... I would not want to get more information into my inbox unless I specifically ask for it." Another stated, "as a young provider, I'm really struggling with that because I have a guilty conscious. I feel like every night, when I go home, I have to check and make sure all my inbox is clear, including MyChart [electronic email patient-provider messaging system]. It makes it pretty impossible for me to take any time for myself." Providers often reported that they wanted to help patients start taking more responsibility for their

medication taking rather than policing it. Another provider reported that team members "try hard to start transitioning them and start encouraging them to take more responsibility. When they start getting 12, 13, 14-ish, depending on their maturity, to start taking more responsibilities."

Rebellion. Both patients and providers indicated that for some teens, not taking their medication is a form of rebellion. When asked to discuss a time when she stopped taking her medication for a long time, one subject reported, "I had just moved out of my grandma's house, and I wasn't really too happy about it. I didn't like where I was living, and so I just didn't wanna take my pills. I didn't take my pills for quite a while. Until they found out that I wasn't taking my pills, and then I started taking them again." This was echoed by providers as well, with one physician stating, "Typically the kids who are transplanted at one, two, or three, or before school <have> very hovering parents, typically. Very controlling. It's very difficult for normal adolescent phase to occur in that process, and it often manifests itself as rebellion, not taking meds, et cetera." Another physician described similar experiences. She reported:

> *Well, two patients that I'm thinking about. One was, really, not trying to do high-risk behavior, but I think was just tired of being a sick kid. In their revolt against being a sick kid and having had enough of that, their only thing that they could control was taking the medicines. They did not take them because that was probably the only part of being sick that they had control over. Alternatively, I just had a patient who was doing beautifully. She just really wanted to piss everybody off in every way possible. Whether that meant wrapping her car around a tree or setting fires in the house or, specifically, having low <medication> levels when she knew we were gonna check them. She just really wanted to irritate the people who were taking care of her.*

mHealth tool development

The mHealth tool designed used the results of the interviews, known efficacious adherence strategies, and self-determination theory (by incorporating features supporting autonomy, competence, and relatedness into intervention content and application design). After several weeks of discussion, the mHealth tool that the research team thought reflected the themes of the interviews (by limiting clinician/health provider workload while encouraging structure and routine) and that was able to incorporate the most features of the intervention map was a game app with no provider portal. This adherence app, named *MedVenture,* is a survival game for both iOS and Android in which the player helps castaways survive while learning and implementing behavioral strategies for medication taking.

Table 1 describes specific features of *MedVenture* and their relationship to both self-determination theory and efficacious adherence strategies. For example, *MedVenture* allows users to "habit-stack" or link their medication to already-formed habits (such as brushing their teeth); this technique provides autonomy support while employing known behavioral strategies.[32] Because the appearance of an avatar can influence relatedness[33] as well as engagement with games,[34–36] particularly if the avatar is perceived to be similar to the player,[36] users of *MedVenture* are able to customize an avatar and its companion friend (a parrot). Figure 3 depicts a screenshot of part of the customization process. To prevent app abandonment and promote engagement with the app, gamification was purposefully employed.[37] Figure 4 shows a screen shot of MedVenture. Players can unlock new features (such as the cooking station depicted in the screenshot), complete challenges (such as repairing the boat with the hammer depicted), and earn points (depicted by the health bars on top of the screenshot). In line with literature showing that reminders are not sufficient on their own to promote adherence[5] and that interventions that focus on automaticity and habit formation are the most effective at improving medication adherence,[7] *MedVenture* specifically reinforces repetition. It also rewards keeping track of whether or not plans for medication taking were made rather than whether or not a medication was taken. *MedVenture* not only allows users to pick their own medication adherence strategy but also provides feedback and the opportunity to change their adherence strategy and support strategies such as setting an alarm.

Discussion

Current literature on the use of technology to facilitate medication adherence for adolescents suggests that although there has been an increase in the use of apps and other technologies for adolescent illness self-management, the data remain limited on whether and how we can use technology effectively for increasing and sustaining medication adherence for this age group.[38] While researchers have made specific recommendations for technology-based strategies to increase adolescent medication adherence, these strategies that have not been tested in rigorous research trials.[39] In this study, we interviewed adolescent liver transplant recipients and healthcare providers regarding barriers to medication adherence. While we initially planned to

Table 1. App features and their relationship to concepts salient to self-determination theory and mobile health design.

Concept	Brief description	App feature(s)
Autonomy support	Feeling in control of behaviors and goals	1. To allow for Habit Stacking: users can link their medication taking to suggested cues or pick their own cue. 2. Ability to change plans if selected cues are not working
Competency support	Needing to feel effective	1. Alarm feature 2. Positive feedback messages and messages of encouragement
Self-identity	Alignment with goals, values, and belief systems	1. Designing an avatar: users can pick the appearance of their avatar including clothing, skin tone, hair color, and secondary sex characteristics. 2. Avatar features relate to the personality of the player. For example, if the player identifies as adventurous, the avatar will be more likely to take risks.
Relatedness	Feeling a sense of belonging	1. Inclusion of a parrot friend to provide company and encouragement
Self-monitoring	Keeping a record of behavior	1. Access to medication adherence log: players can view their medication-taking history
Personalized feedback	Providing information regarding performance	1. Tailored messaging based on adherence with both encouraging and congratulatory messages.
User engagement	Promoting continued use of the app	1. App designed as a game with features such as crafting, challenges, and unlocking of new features. 2. Push-notifications

Figure 3. Screenshot of part of the avatar customization process in *MedVenture*.

use this information to create a mHealth tool and provider portal, our work resulted in the creation of a game app to assist in habit formation and self-management. This work highlights several concepts necessary to the integration of digital health and medicine.

First, end-user engagement and a collaborative team approach are essential to the successful design and

Figure 4. Screenshot of *MedVenture* showing key gamification features. The cooking station is a new feature that can be "unlocked." Users can complete challenges (such as repairing the boat with the hammer depicted) and earn can points to improve their health (depicted by the bars on top of the screenshot).

development of mHealth tools.[40] Exploring patient barriers to medication adherence revealed that rebellion is a source of nonadherence for some patients. While not addressed by *MedVenture*, it is an important concept to measure in future studies assessing effectiveness of adherence interventions. Additionally, the initial idea for our tool changed dramatically based on the input of end-users (both patients and health providers). Consistent with a recent systematic review that showed that providing physicians with feedback regarding their patients' adherence rates led to little or no difference in medication adherence rates,[41] clinicians interviewed in this study did not want a system that required action on their end. Thus, while this study was initiated with the hope of creating an interactive logging tool for patients and providers, the end product was a self-sufficient app to promote habit formation. This is reflective of a paradigm shift in health services research.[42] Stakeholder engagement is encouraged[43]; patients are asked to provide their input; and a robust literature promoting flexible and adaptive study designs has emerged.[44]

Second, mHealth applications are an unexplored way of promoting medication habit formation. Emerging research suggests that digital tools can improve habit and automaticity.[45] Smartphone apps may subsequently represent an important context in which to deliver interventions to improve adherence. Interventions based on real-time feedback have provided insight regarding how context and social situations affect adherence decisions and have been used to effectively improve adherence.[46–48]

Finally, academic and industry collaborations have the potential to be successful in achieving more desirable products. The research team incorporated both subject experts and tech-industry professionals, both of which have been associated with increased app usage.[49,50] Additionally, the team included a research organization (mHealth Impact Lab) that specializes in academic and industry collaborations. Members of the mHealth Impact Lab were well-versed in both health services delivery and technological innovation, thus facilitating conversation between groups of varying backgrounds. In this project, the Impact Lab served as a translator between technological verbiage and medical jargon. Trustworthiness of an app is a major factor in clinician recommendation to their patients[51] yet the majority of adherence-related apps are industry

based.[52] While over 70 digital health centers exist in academic health centers,[53] their utility in research is often not described. Thus institutions that have structures in place to promote industry-academic collaborations may be able to bridge the gap between commercial appeal and academic credibility.

While this study depicts the product of a successful partnership between academics and industry, there are several limitations. First, only four patients and four healthcare providers were interviewed. While three themes emerged from qualitative analysis, it is possible that more themes would be identified with a larger sample size. Second, while rebellion was noted as a theme in medication nonadherence, it was not addressed by *MedVenture*. Although it is unclear if rebellion can be feasibly addressed with an app, questions regarding rebellion should be incorporated into studies examining app efficacy. Finally, patients have not yet tested *MedVenture* in practice. However, a major strength of this work remains that patient and provider input was incorporated early in the design process. Several studies have shown that early involvement promotes better engagement[54,55] and that when given the choice among many apps, users have preferences for preferred features of health-related apps.[56] This is of particular importance in designing interventions for adolescents given that adolescence is a critical period in the development of routines and self-management skills, and digital interventions designed for adults may not address an adolescent's unique developmental and psychosocial barriers.[39]

This manuscript highlights the importance of patient and healthcare provider involvement in the design of mHealth interventions and explores the use of academic-industry collaboration to combine health behavior theory and end user-engagement strategies. This is in line with recent studies during the COVID-19 pandemic describing that perhaps providers can leverage technology to address psychosocial barriers in children and adolescents with chronic diseases.[57] Additionally, the rapid uptake of technology in healthcare delivery during the COVID-19 pandemic has taught us that digital approaches to healthcare delivery are necessary but that there are many unanswered questions including cost-effectiveness and system readiness for adoption (including both academic and community settings).[58] While this manuscript describes the initial development of a mHealth tool (*MedVenture*), future work is needed for successful implementation in real-life settings. Because barriers to technology use are more common for those who live in rural areas, racial/ethnic minorities, those with low socioeconomic status, and limited English proficiency, clinicians and researchers should continue to advocate for policy changes.[59] Next steps for MedVenture specifically include conducting user acceptance testing of *MedVenture* by testing the usability – or the extent to which a product can be used by its target users to effectively achieve its goal. Our goal is to use an iterative approach and conduct three rounds of user testing with app modification between rounds. The final app prototype will then be tested in a larger randomized controlled trial measuring not only app usage but also effect on habit/automaticity, medication adherence, and disease outcomes. Finally, given the lack of economic data to support the use of digital interventions,[60,61] future testing of *MedVenture* should include cost-benefit analysis.

Conclusions

In this manuscript, we describe the development of a mHealth tool using the integration of health-behavior theory, planning and habit formation techniques, and user engagement to promote medication adherence in adolescents who had undergone liver transplantation. We found three major themes regarding medication nonadherence in this patient population: lack of routine prevents adherence to treatment, healthcare providers prefer digital health tools that promote patient self-management rather than health provider monitoring, and some patients use nonadherence as a form of rebellion. This engagement of stakeholders including patients and healthcare providers changed the initial design of the mHealth tool from an interactive patient-provider medication logging portal to a game-based app to improve habit and planning. Finally, this app is representative of successful academic-industry collaboration and may lead to better acceptance by both patients and the medical community. Future research regarding the testing of this app, cost-effectiveness, and its effect on habit formation and adherence are needed.

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