Learning experience design of an mHealth self-management intervention for adolescents with type 1 diabetes

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Abstract

Type 1 diabetes (T1D) is a lifelong and chronic condition that can cause severely compromised health. The T1D treatment regimen is complex, and is a particular challenge for adolescents, who frequently experience a number of treatment adherence barriers (e.g., forgetfulness, planning and organizational challenges, stress). Diabetes Journey is a gamified mHealth program designed to improve T1D self-management through a specific focus on decreasing adherence barriers and improving executive functioning skills for adolescents. Grounded in situativity theory and guided by a sociotechnical-pedagogical usability framework, Diabetes Journey was designed, developed, and evaluated using a learning experience design approach. This approach applied design thinking methods within a Successive Approximation Model design process. Iterative design and formative evaluation were conducted across three design phases, and improvements were implemented following each phase. Findings from the user testing phase indicate Diabetes Journey is a user-friendly mHealth program with high usability that holds promise for enhancing adolescents’ T1D self-management. Implications for future designers and researchers are discussed regarding the social dimension of the sociotechnical-pedagogical usability framework. An extension to the framework is proposed to extend the social dimension to include socio-cultural and contextual considerations when designing mHealth applications. Consideration of the pedagogical and sociocultural dimensions of learning is imperative when developing psychoeducational interventions.

Keywords Type 1 diabetes · Executive functioning skills · mHealth · Adolescents · Self-management · Successive Approximation Model

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Introduction

The purpose of this article is to detail the design, development, and learner-centered evaluation of Diabetes Journey, a novel mobile health (mHealth) and telemedicine intervention for adolescents with type 1 diabetes (T1D) designed to promote problem-solving around identified T1D adherence barriers. Gamification elements and a highly interactive mobile interface are used to provide adolescents with an appealing and engaging multimedia learning experience. Diabetes Journey uses an amusement park theme to provide a light and playful atmosphere. Individualized learning modules are provided to adolescents and tailored to their individual needs in the areas of stress/burnout and time pressure/planning. Learning content focusing specifically on these two areas is presented as a series of amusement park attractions that adolescents visit (e.g., Burnout Bumper Cars, Planning Parachutes). Adolescents earn awards such as digital badges and achievements by completing activities at the attractions/modules. Friendly characters (i.e., pedagogical agents) guide adolescents through the amusement park, providing coaching, feedback and encouragement. Usage is monitored and presented in such a way that adolescents can keep track of their progress and readily identify what was learned at each attraction.

T1D is a chronic condition in which the body is unable to produce insulin, a critical hormone in the pancreas that regulates blood glucose. The goal of T1D treatment is to achieve near-normal blood glucose levels via a complex constellation of medical and behavioral provisions, including glucose monitoring, carbohydrate counting, and insulin administration in response to a variety of factors including food intake, exercise, stress, and illness. Optimal engagement in these T1D-specific behaviors is a particular challenge for adolescents (Datye et al., 2015; Miller et al., 2015). Difficulties in self-management in adolescents with T1D can lead to out-of-target blood glucose and potentially result in acute and chronic complications, such as increased risk of hospitalizations from severe hypoglycemia or diabetic ketoacidosis, and reduced overall health-related quality of life (Burdick et al., 2004; Miller et al., 2013; Realsen et al., 2012). One key to monitoring glycemic levels is the hemoglobin (A1c) measurement, which serves as a reflection of one’s estimated average glucose for the past three months (NIDDK, 2018). Although the American Diabetes Association (ADA) currently recommends an A1c of less than 7.0% for adolescents with T1D (Redondo et al., 2021), T1D Exchange data found that the average A1c for this group was 9.3% (Foster et al., 2019). Further, they report that only a small subset of youth (17%) met even the previous 2018 ADA recommended glycemic target of less than 7.5%. These findings from the T1D Exchange demonstrate a worsening in adolescents’ glycemic levels over time, despite the increased uptake in diabetes technology (i.e., insulin pumps and continuous glucose monitors). This is a public health concern that highlights the need for improved T1D self-management tools above and beyond diabetes devices.

T1D self-management behaviors and patterns are established early in adolescence, may persist over time, and can influence subsequent health outcomes in adulthood (Kovacs et al., 1992). Promoting effective T1D self-management behaviors in adolescents is a complicated process, due in part to an immature inhibitory control system (i.e., emerging executive functions). Developmentally, adolescents are motivated by novel experiences and predisposed to impulsive and risky behaviors (Casey & Caudle, 2013). As a result, adolescents are less likely to engage in behaviors that do not lead to immediate rewards, such as completing blood glucose checks or administering insulin in a timely manner, as these tasks often compete with other daily demands and do not have immediate rewards. In addition, they are less likely to appreciate the negative consequences of their decisions on
their future health status (Casey & Caudle, 2013). Given the link between suboptimal T1D self-management behaviors and subsequent glycemic control (Burdick et al., 2004; Miller et al., 2013), it is unsurprising that, on average, A1c levels in 13–17 year-olds remains substantially higher than that recommended by the ADA (Foster et al., 2019).

Research suggests that behavioral factors have strong associations with adolescent T1D self-management and health outcomes (Kichler et al., 2012; Sarteau et al., 2020). Two prominent behavioral factors include (1) stress and burnout and (2) executive dysfunction related to time management and planning (Miller et al., 2015; Mulvaney et al., 2011; Perez et al., 2017). Although some interventions have targeted the barriers of stress/burnout and aspects of executive dysfunction (i.e., poor planning) for adolescents with T1D in research and clinical practice (Hagger et al., 2016; Miller et al., 2020), using a mobile health technology platform to deliver the intervention is an area that remains largely unexplored (Knox et al., 2019). This signals a need for behaviorally-focused interventions to promote improved glycemia through identifying and targeting the barriers that impact adolescents’ T1D self-management on a technology platform that can be easily accessible to a wide variety of patients, including those with suboptimal glycemic levels (Kalyani et al., 2018; Knox et al., 2019; Petitti et al., 2009). Diabetes Journey was developed to address this need.

In the current study, the design, development, and evaluation of Diabetes Journey is presented from the perspective of learning experience design (LXD). We begin by providing background on technology-based interventions for adolescents with T1D, with a specific focus on mobile health tools and how these influenced our own design practice based on both research findings and identified limitations. We then outline the theoretical and methodological underpinnings of our design with a specific focus on how situativity theory influenced our application of LXD methods and processes. This is followed by an overview of our design and development processes. Finally, we present the methods and findings from patient-centered user testing, detail how those findings reflexively influenced design in subsequent iterations, and discuss the implications.

mHealth tools for adolescents with T1D

Many mobile apps have been developed to manage diabetes (Chavez et al., 2017). Research on mHealth for adults with T1D illustrates potential health benefits, such as actively engaging people in self-management of their medical conditions (Handel, 2011), allowing timely interventions based on user behaviors (McCurdie et al., 2012), providing individualized healthcare at the patients’ convenience (Kirwan et al., 2013), and decreasing the burden of in-person T1D clinic visits (Marker et al., 2019a, 2019b; Markowitz et al., 2014). For example, Kirwan et al. (2013) used a freely-available iPhone app to examine the effectiveness of an mHealth tool in combination with text-message feedback, with findings suggesting improved A1c relative to a control group who received standard of care.

Although benefits of using mHealth tools for adults with T1D are promising, studies with a specific focus on supporting adolescents with T1D are more limited. Most mHealth tools have been developed for younger children (e.g., Albanese-O’Neill et al., 2019) or do not assess key clinical outcome variables—especially for those with suboptimal glycemic levels (Knox et al., 2019). Nonetheless, research suggests youth with T1D and their caregivers value mHealth tools for managing diabetes (Knox et al., 2019).

Use of mHealth for adolescents with T1D is supported by this demographic’s ubiquitous use of smartphones and tablets. According to Pew Research Center (Smith, 2015),
approximately 90% of adolescents have cell phones (73% smartphones), 90% of which use cell phones for text messaging and 91% for accessing the internet (with a notable increase in use for minority youth). However, the following limitations have been noted in the literature regarding the potential of mHealth tools to improve T1D care and health outcomes for adolescents:

1. Effective education and self-management principles, such as cognitive, behavioral, and social strategies (including goal-setting, problem-solving and motivational techniques) have not been systematically incorporated into these technologies;
2. Self-management tools currently available are “didactic and do not provide patients with the personalized and actionable knowledge needed to participate in routine self-care” (Goyal et al., 2016, p. 96), which is associated with low rates of uptake;
3. Engagement factors are largely missing in existing products, which decreases the effectiveness of those products in achieving their goals (Årsand et al., 2012);
4. Many products lack theoretical foundations and/or alignment with technology-based learning principles (Whittomere et al., 2010); and
5. Robust product evaluation is often lacking (e.g., Albanese-O’Neill et al., 2019; Whittomere et al., 2018).

In the current article, special attention is made to address these limitations. For example, Diabetes Journey intentionally focuses on topics such as tips for problem-solving and executive functioning, areas that were recommended in several studies as future research directions for diabetes-related products (Adu et al., 2018; Sarteau et al., 2020; Weissberg-Benchell et al., 2020). Further, Diabetes Journey supports personalized learning experiences and provides actionable knowledge for target learners to better handle identified T1D adherence barriers. Research suggests designs informed by target learners’ feedback and preferences could potentially lead to higher levels of target learner engagement (Conway et al., 2016; Lee, 2011). To influence the level of engagement of adolescents with T1D, we adopted a learning experience design approach (Schmidt et al., 2020a, 2020b), which allowed us to engage target learners across all phases of iterative design.

Conceptual framework

mHealth product design and development varies from study to study and lacks systematic principles to guide the design process (Whittemore et al., 2010). Examples of applying learning theory and principles in the intervention development process are rare. Of these, Kok et al. (1997) used certain principles from social learning theory to investigate determinants of effective knowledge processing and to facilitate development of a user-friendly interface for their web-based intervention. Goyal et al. (2016) adapted Graham’s Knowledge to Action (KTA) model and Medical Research Council’s (MRC) blended framework for the design and evaluation of an mHealth intervention. This intervention facilitated a user-centered learning experience and promoted significant behavior change in users. Considering behavior change theory, Whittemore et al. (2020) used a systematic approach, formative research, and collaboration with stakeholders to adapt evidence-based novel diabetes self-management education programs to local contexts and create a culturally-relevant learning experience for local patients. Although learning theories and principles have been adopted to varying degrees in mHealth product design and development, the primary
principles that guide learning design in this context appear mostly to be based on intuition, experience, and clinical judgment (O’Neil, 2008; Yanchar et al., 2010). mHealth research potentially could benefit from the theoretical, methodological, and design perspectives of fields such as learning design and user experience design (Maramba et al., 2019; Tamim & Grant, 2016).

Learning experience design

The development of Diabetes Journey adopted a learning experience design (LXD) approach. LXD is “a human-centric, theoretically-grounded, and socio-culturally sensitive approach to learning design, intended to propel learners towards identified learning goals, and informed by user experience design (UXD) methods” (Schmidt & Huang, 2021, p. 151). While UXD focuses on general users engaged in general computing tasks, LXD focuses on a specific class of user—the learner—engaged in a particular activity—digitally-mediated learning. LXD acknowledges the centrality of the learner within the learning context, is informed by learning theories such as situativity theory (e.g., Brown et al., 1989), and adopts UXD methods such as usability testing, focus groups, and development of personas to inform the design, development and evaluation of interventions (Schmidt et al., 2020a, 2020b). LXD involves iterative processes such as assessing learner needs, translating key concepts into prototypes, and constantly refining prototypes through usability testing (Marker et al., 2019a, 2019b; McCurdie et al., 2012). In healthcare contexts, related methods are often presented as patient-centered design or user-centered design (Cornet et al., 2020; Graham et al., 2021), and generally consist of iterative processes that can elicit perspectives from multiple stakeholders to maximize content accuracy, material usability, and optimize the experience for the target audience. Techniques such as focus group interviews, field testing, and ethnography studies are also frequently used to understand different stakeholders’ needs (Schmidt et al., 2020a, 2020b).

Related to LXD are user-centered design and evaluation methods, an area of increasing need in mHealth intervention design (Whittemore et al., 2020). Few interventions developed for youth with chronic conditions adopt user-centered, patient-centered, or learner-centered methods. As a result, many products have not been optimized for usability or evaluated for feasibility, acceptability, utility, etc. (Årsand et al., 2012). However, user-centered methods such as usability testing and focus groups can yield a more comprehensive view of product needs (Georgsson & Staggers, 2016); can unveil adolescents’ challenges to T1D self-management, content needs, and usability issues of mHealth (Whittemore et al., 2020); and can give insights into issues that might influence intervention efficacy such as overall usage, preference for technology use, and general trend of using technologies for diabetes management (Yu et al., 2014). A range of usability methods have been reported in the literature (Georgsson & Staggers, 2016); however, systematic methods to validate designs are lacking (Garabedian et al., 2015), which has resulted in mHealth technologies that are often not intuitive, appealing, or useful (Goyal et al., 2016).

Acknowledging the centrality of the user (i.e., patient) is essential in understanding mHealth user needs and improving intervention specifications, design, and testing so as to match the functionality of mHealth with users’ developmental and cognitive abilities and needs. Examples of this include (1) Albanese-O’Neill et al. (2019) involvement of fathers in the development process of an online diabetes self-management education and support system, (2) Cafazzo et al. (2012) use of a social community to inform their design, (3) Yu et al. (2014) user-centered design of a self-management mHealth app to promote behavior
change in patients, and (4) the user-centered approach described by McCurdie et al. (2012) that led to an app that helped reduce social stigma and helped users stay engaged. A common approach to user-centered design in general and in health education contexts specifically is usability evaluation, which seeks to examine users’ perceptions of effectiveness, efficiency, and satisfaction with systems, products, or services within a specific usage context (cf. International Organization for Standardization; ISO, 2018).

A range of methods and instruments have been developed and applied to test product usability, for example, Nielsen’s widely-used heuristics (1994a), the scenario-based usability testing method (e.g., Granić et al., 2020; Johnsen et al., 2016), and IBM’s Computer System Usability Questionnaire (Lewis, 1995). However, these methods and instruments mainly focus on technological usability, which researchers suggest may be insufficient when evaluating applications in learning or educational contexts (Lim & Lee, 2007; Reeves, 1994). This tension has led to calls to extend usability evaluation of educational technologies to include pedagogical considerations (Granić & Ćukušić, 2011; Jahnke et al., 2020; Pham et al., 2019), as well as social interactions and the social roles of users (Gamage et al., 2020; Jahnke et al., 2021). Responding to this tension, Jahnke et al. (2020) analyzed 13 articles with usability evaluation criteria, and categorized them into three dimensions: (a) technological (e.g., Nielsen’s 10 heuristics, navigation, learnability), (b) pedagogical (e.g., learner context, learning activities, learner control, tasks), and (c) social (e.g., collaboration, communication, roles and/or relationships, social interactivity). Based on their results, they proposed a multi-dimensional usability framework that considers usability along these three dimensions, which they refer to as sociotechnical-pedagogical (STP) usability. We adopted the Jahnke et al. (2020) STP heuristics for design and evaluation of Diabetes Journey, including, clear instructions for using technology and navigating (technological), promoting positive social interchanges (social), and providing clear organization of activities and meaningful assessments (pedagogical).

Situativity theory

The sociocultural context through which learners make meaning is an “influential and inevitable” aspect of how we learn (Tessmer & Richey, 1997, p. 88) that supersedes and subsumes cognitive, physiological, affective, and social (as in the social dimension of STP) considerations (cf. Smith & Ragan, 2004). Situativity theory (e.g., Brown et al., 1989) asserts that knowledge, thinking, and learning are situated in learners’ experiences. These experiences include lived experience, culture, and physical environments. Situating learning within experience, culture, and context can promote powerful learning experiences. It can: (1) provide a lens through which negotiation of meaning can occur (Vygotsky, 2012), (2) shape cognition (Järvenoja et al., 2015), (3) influence recall of prior knowledge, (4) enhance meaning (Shepherd, 2011), and (5) promote transfer of knowledge and skills to novel situations (Tessmer & Richey, 1997). Within this sociocultural frame, “acts take their meaning in relation to the social worlds (or communities of practice or activity systems) in which individual actors participate and to the actors’ positions or identities in those contexts” (Nolen, 2020, p. 1). This, in turn, can influence learner motivation (Li et al., 2010; Nardi, 1996; Turner, 2001).

Importantly, LXD specifically considers how sociocultural factors influence learners’ experiences with a digital learning intervention (Schmidt & Huang, 2021). Sociocultural factors are important to design “not because members of one gender or racial group process information differently, but because members of a gender, ethnic, or racial group tend to
have common experiences due to their group membership that may be quite different from those had by members of other groups” (cf. Smith & Ragan, 2005, p. 50). In the realm of mHealth, sociocultural factors have been shown to influence intervention outcomes. For example, the social context of family has been found to shape beliefs and practices of diabetes management (Whittemore et al., 2020). However, emphasis on sociocultural considerations is limited, despite calls for greater attention (e.g., Mayberry et al., 2020), an issue we speak to in the current research

Program description

Diabetes Journey is designed to reduce barriers to adherence, including decreasing diabetes-related stress and enhancing executive functioning skills related to T1D management. Recognizing adolescents’ developmental need for autonomy, adolescents with T1D can access Diabetes Journey at any time. The program is cross-platform compatible and can be used on a smartphone, tablet, or laptop/desktop computer. Diabetes Journey was developed using a modified version of the open source WordPress content management system (https://wordpress.org/). Diabetes Journey incorporates a variety of gamification elements within an overarching amusement park theme (Fig. 1). Adolescents with T1D learn how to better manage their T1D care and overcome barriers by navigating through nine amusement park attractions (learning modules), engaging with highly interactive learning content, and earning rewards (e.g., digital badges and certificates). A full listing of these

Fig. 1 Diabetes Journey homepage illustrating the amusement park map from which users can select different attractions to visit
attractions is provided in Table 1. The lessons and learning objectives that are presented in the theme park’s attractions are reinforced later via telehealth sessions with a trained therapist.

The Diabetes Journey learning experience is tailored to address the specific needs of participants. This is accomplished by first assessing acute areas of need using a survey, and then providing a set of learning modules that are tailored to those areas of need. The survey instrument is the Barriers to Diabetes Adherence scale (BDA: Mulvaney et al., 2011). From this scale, learners assigned customized learning content corresponding to their scores on two subscales of the BDA: (1) Stress and Burnout and (2) Time, Pressure, and Planning. Some modules are common to all learners. For example, all learners begin at the Ticket Booth, an introductory module where they are greeted by two pedagogical agents in the form of relatable avatars who accompany them on their full journey through the amusement park (Fig. 2). Upon successful completion of the Ticket Booth, learners receive an entry ticket that opens up the theme park attractions. Learners can use this ticket to access the attractions that are associated with the learners’ custom learning trajectory, i.e., Stress and Burnout or Time, Pressure, and Planning. If only one BDA subscale is elevated, learners receive five modules. If both subscales are elevated, learners receive eight modules. After modules are assigned learners can visit various attractions in the amusement park in any order. On average, an attraction takes around 20 min to complete.

Diabetes Journey also incorporates various gamification features (Huang et al., 2020; Laine & Lindberg, 2020). The entire learning environment is presented as a game that takes place within a theme park. Module selection takes place on a map, much like a level selection screen on a video game. Coach Frank and Maxine act as non-player characters (NPCs). A subscreen is used to display player stats, achievements, and progress. In addition, a role-playing mini-game is provided in the Pirates of Problem Solving attraction in which the learner finds themself at a party but has forgotten their insulin and supplies. The learner must navigate a series of challenges in order to get home safely and then develop a plan for avoiding this problem in the future (Fig. 3).

Learners are able to control the pace of their learning in that they can stop at any time and pick up where they left off. Content is personalized based on learner inputs. For example, pedagogical agents refer to the learner by their name and refer to information and decisions the learner has made when providing feedback. Upon completion, learners can review what has been covered and download certificates of completion.

**Methodology**

The purpose of the current project was to apply LXD methodology to create and evaluate the Diabetes Journey intervention for adolescents with T1D. Allen and Sites’ (2012) Sequential Approximation Model 2.0 (SAM2) was used to iteratively advance our design through three phases: (1) preparation, (2) iterative design, and (3) iterative development. We operationalized the three broad phases of SAM using design thinking methods and processes (Altman et al., 2018). Our iterative LXD processes were guided by ongoing formative evaluation, which sought to provide insight into the following questions:

RQ1 How do participants characterize the usability of Diabetes Journey?
RQ2 What is the nature of learner experience with Diabetes Journey?
RQ3 How might usability and learner experience be improved?
| Theme park attraction       | Description                                                                 | Group                          |
|----------------------------|-----------------------------------------------------------------------------|--------------------------------|
| Ticket booth               | Includes information about how to use this program and provides an overview of what learners will learn in each learning module | All learners                   |
| Pirates of problem solving | Focuses on the five-step process to solving problems associated with T1D and includes an interactive role-playing game | All learners                   |
| STRESSOLATOR               | Focuses on strategies to cope with stress and worries                       | Stress and Burnout group       |
| Memory monorail            | Focuses on skills to improve memory and attention                           | Time, pressure, and planning group |
| Planning parachutes        | Focuses on strategies to improve organization and planning skills           | Time, pressure, and planning group |
| Burnout bumper cars        | Focuses on developing an understanding of T1D burnout and introduces important ways to bring oneself out of burnout | Stress and burnout group       |
| The mood swing             | Helps learners in identifying, managing, and expressing emotions           | Stress and burnout group       |
| The inhibitor              | Focuses on how to stop and think before acting as well as taking control    | Time, pressure, and planning group |
| Closing time               | Concludes what learners have learned during the visit and provides practice problems which assess learners’ learning outcomes | All learners                   |
Fig. 2 Screenshot from smartphone of Diabetes Journey’s pedagogical agents, Coach Frank and Maxine (left) and a sample interactive activity (right)

Fig. 3 Diabetes Journey problem-solving video game in which learner (1) selects from non-binary gender options, (2) views character, (3) makes decisions that influence the outcome of the game, and (4) receives badges and tracks progress
LXD is rooted in the tradition of design thinking (Schmidt & Huang, 2021), informed by UX methods, and applied in the context of learning and instructional design (Schmidt et al., 2020a, 2020b). Correspondingly, our LXD process aligned and merged design thinking and SAM2 processes to structure and inform our design practice. SAM2 is a recasting of the five phases of the ADDIE instructional design process model (analyze, design, develop, implement, and evaluate) within an agile software development framework (Allen & Sites, 2012). SAM2 is appropriate for rapid instructional design projects that intentionally seek input from stakeholders and users across the full arc of design and development—from the concept phase to roll-out of the final product. SAM2 is particularly useful for conceptualizing and communicating design across a variety of stakeholders (e.g., subject matter experts, project owners, potential users, design team, development team, etc.); however, SAM2 does not explicitly prescribe methods. Therefore, in order to further inform our SAM2 process, specific methods were identified from the tradition of design thinking.

- According to the Stanford Design School, design thinking is “a methodology for creative problem solving” (Stanford d.school, 2008, para. 1). This methodology consists of five iterative stages: (1) empathize, (2) define, (3) ideate, (4) prototype, (5) test. UXD methods are often applied within these stages, including empathy mapping, development of personas, iterative rapid prototyping, and usability testing (Ahmed et al., 2018; Baig et al., 2020; Rapp, 2020; Tonkin et al., 2018). Recent trends suggest that methods such as these also have found resonance in the field of learning and instructional design (Schmidt et al., 2020a, 2020b). Merging design thinking with SAM2 required articulation of each stage of the design thinking process and then aligning with SAM2 phases (Fig. 4). The design thinking stages include:
  - **Empathize** LXD tasks in this design stage include front-end analysis such as learner/context analysis, document review, literature/product review, empathy interviews, empathy mapping, and the creation of personas.
  - **Define** LXD tasks in this design stage include identifying design principles and defining requirements.
  - **Ideate** LXD tasks in this stage are informed by: (a) learner considerations (patients in this case), (b) technological considerations, (c) pedagogical/theoretical considerations, and (d) subject matter expert (SME) input.
  - **Prototype** During this stage, design ideas generated in the ideate stage are instantiated and delivered in rapid iterations via different forms of prototypes. These may focus on individual elements of the broader design (i.e., how coaches should look and communicate, sketches of the amusement park map, etc.) or the integration of all (such as wireframes and functional prototypes that demonstrate how the full intervention should work).
  - **Test** Multiple LXD evaluation methods may be used at this stage to interrogate the learner experience, such as task-based think-alouds, heuristic evaluation, analytics, questionnaires, etc. Testing results are then fed back into the design and development process across further iterations.

Mapping of design thinking stages to SAM2 phases was bidirectional. While Fig. 4 illustrates how the design team operationalized the stages of design thinking across the SAM2 process, it does not illustrate how methods commonly used in design thinking were applied within the SAM2 phases. How UX methods were applied within SAM2 phases in the design of Diabetes Journey is illustrated in Fig. 5, which details how the design of
Diabetes Journey unfolded in an iterative manner across three phases: (a) Phase 1: Preparation, (b) Phase 2: Iterative Design, and (c) Phase 3: Iterative Development. In the following sections, each of these phases is discussed, and the inputs, processes, and outcomes of each phase are described.

**SAM phase 1: preparation**

An overarching goal of Diabetes Journey was to design intentionally for adolescents with T1D. Adolescents with T1D must engage in T1D self-management tasks within the context of their influential peer and social relationships, which can have both a positive and negative impact on behaviors (Markowitz et al., 2015). Moreover, an adolescent may perceive that T1D situations are embarrassing and thereby avoid...
self-management tasks, given that they are not as comfortable navigating and problem-solving within these situations. In addition, the successful transfer from parents/caregivers to the adolescent for the responsibility of their T1D self-management is also another fundamental barrier to overcome during this developmental stage (Markowitz et al., 2015). So, as parents/caregivers shift away from taking primary responsibility for T1D self-management decisions, there can be decision-making and planning challenges that impact the adolescents’ T1D care and, ultimately, their glycemic levels during this developmental period. Taken together, this can lead to emotional (stress and burnout) as well as behavioral (time pressure and planning) barriers to effective self-management. Therefore, we engaged in a series of preparatory steps, which were used to inform and develop our initial prototype in a manner that sought not only to consider learner needs, but to truly empathize with adolescents and the challenges with T1D they face on a daily basis.

Development of empathy is essential for designers to understand the interconnected roles of ethics, values, and lived experiences in the design process (Gray et al., 2015; Strobel et al., 2013). Specific methods that informed the preparation phase included: (1) learner analysis and content analysis, (2) document review, (3) literature and product reviews, and (4) empathy interviews. First, learner analysis sought input through SME interviews, empathy interviews with individuals with T1D, and perusal of documentation provided by the SMEs. Content analysis was conducted by performing a thorough review of draft educational content provided by the SMEs, segmenting and sequencing the content, and developing draft learning objectives. Second, document review referenced the grant narrative and the validation study of the Barriers to Diabetes Adherence scale (Mulvaney et al., 2011). Third, literature and product reviews were performed to develop a repertoire of design principles that had been specifically applied with adolescents with T1D, as well as a set of projects to reference as design precedents to inform ideation and prototyping (Boling & Frick, 1997; Gibbons, 2003; Gray et al., 2015). Fourth and finally, a series of empathy interviews were conducted, which were used to perform empathy mapping and develop a set of patient personas (Fig. 6).
Empathy interviews, empathy mapping, and personas development

We performed a total of four empathy interviews with adolescents with T1D. The purpose was to learn what was important to participants, to reveal emotional and perhaps tacit insights, to explore behaviors, needs, and challenges, and, ultimately, to develop a deep understanding for the daily lived experiences of an adolescent with T1D. Different from more traditional interview methods, empathy interviews aim to promote true understanding of their perspective, which requires interviewers to immerse, observe, and engage during the interviews (Doorley et al., 2018). This method allows designers to learn how potential target learners feel about a central problem and how they might perceive designed solutions, thereby enabling designers to develop shared understanding and experience. Ultimately, empathy interviews can serve as a conduit that can promote the emotional disposition of empathetic concern (Warren, 2018) and the cognitive dimension of perspective-taking (Gasparini, 2015) for LX designers. Empathy interviews took the form of a series of open-ended questions tailored to adolescents with T1D. Interviews were performed by a trained postdoctoral fellow while a clinical research coordinator kept notes. We engaged in one-on-one conversations to elicit stories about the specific experiences of interviewees related to T1D. Interviewers followed an expert-developed protocol to help advance “the principles of being intentional, human-centered, and equity-focused” (Nelsestuen & Smith, 2020, p. 60). Interviews were audio recorded and, upon completion, were transcribed for further analysis.

Empathy interviews were analyzed using empathy mapping methods (Siricharoen, 2021; Thompson et al., 2016). Empathy mapping was originally developed as a tool for gamestorming (Gray et al., 2015). To create an empathy map, we categorized excerpts from interview notes and transcriptions based on what the interviewee was saying, doing, thinking, and feeling. The newly organized information then helped the design team focus on the interviewee’s emotions and experiences. These empathy maps were compared to identify themes that appeared in more than one map. Empathy maps were then used to inform the development of learner personas. Personas are archetypes of users who might employ the technology within their specific usage context (Miaskiewicz & Kozar, 2011). In LXD, personas are archetypes of learners who might engage in a learning activity using a learning technology (e.g., LMS, mobile app, serious game). Personas provide “another form of focusing on the problem rather than on an already identified solution; by keeping the learner front and center, designers are humanizing the design problem” (Galyen et al., 2020, para 30). A persona typically

![Fig. 6 Process of empathy interviews, empathy mapping, and development of patient personas](image)
includes information about a user’s demographics, goals, needs, typical day, and experiences. Figure 7 is an example of one of the personas, “Vanessa”, we developed in our LXD process.

**Design principles**

On the basis of the front-end analysis described in the previous sections, we developed a set of design principles (Table 2). These design principles were articulated using the design vocabulary proposed by Kali (2006). This framing relies on a hierarchy to describe design principles using three levels of generalization, (1) specific principles, (2) pragmatic
Table 2  Meta-, pragmatic, and specific design principles used to guide design and development of Diabetes Journey

| Examples of pragmatic principles                                                                 | Examples of specific principles                              |
|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| **Meta-principle 1: Ensure content is clear, accessible, and trustworthy**                      | • Short sentences and paragraphs                               |
| • Make content accessible for learners with varying literacy levels                             | • Liberal use of videos and narrated animations                |
| • Provide simple, clear instructions for interactive activities; reinforce with coaching        | • Limited text on each screen                                 |
| • Use multiple representations                                                                  | • Content at 6th grade reading level                           |
| **Meta-principle 2: Promote intentional interaction with learning materials**                   | • Informal language                                            |
| • Make progress dependent on interaction with learning materials                                | • Progress monitoring                                         |
| • Provide opportunities for varied forms of interaction                                         | • Substantial variety in interactive activities (e.g.,        |
| • Create a clear and engaging flow of interactive activities                                    | flip cards, drag-n-drop, etc.)                                |
| **Meta-principle 3: Create a space that can serve as a reprieve from potential negative emotions (e.g. stress, anxiety, depression, etc.)** | • Digital game-based learning activities                      |
| • Instill a sense of cheer and joy in visual and interaction design                             | • Playful activities                                           |
| • Provide guidance on managing emotions                                                          | • Pedagogical agents exhibit positive, encouraging demeanor   |
| • Integrate positive reinforcement in the form of rewards and incentives                        | • Relevant content on topics of emotion management            |
| **Meta-principle 4: Promote inclusion**                                                          | • Colorful interface components (e.g., buttons, icons)        |
| • Create a, non-judgemental environment for learning                                             | • Cheerful amusement park theme                               |
| • Embed encouraging, inclusive stories                                                           | • Content that acknowledges and validates learners’ situations and feelings |
| • Deliver just in time guidance from empathetic, understanding coaches                          | **Meta-principle 5: Provide for a personalized/customized learning experience** |
| **Meta-principle 5: Provide for a personalized/customized learning experience**                 | • Realistic case scenarios                                    |
| • Attune experience to individual needs                                                          | • Similar feelings/experiences as described by peers          |
| • Design prompts for planning and monitoring                                                    | • Coach and more knowledgeable peer (Coach Frank and peer Maxine) use inclusive, encouraging language |
| • Encourage reflection                                                                          | • System reacts to individual information                     |
| • Provide individualized feedback                                                               | • Role-playing in digital game-based learning activity        |
|                                                                                                 | • Ability to review and reflect on what was learned           |

principles, and (3) meta-principles. Specific design principles describe single features. Pragmatic principles connect multiple specific principles. Meta-principles “capture abstract ideas represented in a cluster of Pragmatic Principles” (p. 190).

**SAM phase 2: iterative design**

The iterative design phase proceeded on the basis of the processes and outcomes of the preparation phase, including personas, design principles, etc. As illustrated in Fig. 5, patient considerations, technological considerations, pedagogical/theoretical considerations, and subject matter expertise (SME) input influenced continually evolving designs and prototypes in many areas, including learning activities, user interface, notifications.
and feedback, etc. Given the emphasis of the current article on LXD, we specifically focus in this section on how we sought to embody the lived experience of adolescents with T1D in the design of the Diabetes Journey and how this learner-centered focus influenced the entire design process. Our intent was to foster a learning experience that was socioculturally relevant to this distinct group of learners. To this end, we began by developing a series of three themes that sought to describe what having diabetes is like. During empathy interviews, participants were presented these three themes with the prompt “Which of these examples do you like best?” This was followed with further elaboration on the theme and further questions. The themes and theme descriptions are as follows:

- Having diabetes is kind of like a hot air balloon: I can have a wonderful experience if I take precautions and know what to expect, but I have to expect some unpleasant feelings, and sometimes the landing might be a little bit bumpy.
- Having diabetes is kind of like a journey by sea: If I manage everything well, I can have an amazing experience, but I have to be vigilant to ensure my safety, I must always keep an eye on the sea, and I must avoid potential dangers.
- Having diabetes is kind of like a maze: I start out by venturing into the unknown, not really sure of what to expect or how to get to the end; I have to apply my problem solving skills and plan various strategies; I have to be flexible, patient, and persistent—there are multiple paths, but only one way to get out.

Feedback from participants on the themes was mixed. No single theme was universally preferred. While participants identified with the descriptions of the metaphorical themes, they did not identify with the actual metaphors themselves. For example, in response to “I will experience a sense of satisfaction at having beat the maze,” a participant stated, “You learn a lot at diagnosis and figure out how it works for you. You get a sense of satisfaction when you have a ‘good’ day.” Ultimately, no single metaphor was able to capture the rich tapestry of diverse perspectives that participants relayed regarding their life with T1D. Nonetheless, participants did perceive each metaphor as having value and being useful to describe certain aspects of T1D. The design team reasoned, therefore, that instead of a single metaphor, a more flexible approach was needed that potentially could capture a range of diverse perspectives; hence, a theme that would allow for multiple metaphors was needed.

Some participants suggested additional themes, with one standing out. Participant 1001 stated, “having diabetes is kind of like riding a roller coaster because having diabetes is really up and down; it can be hard to get a steady blood sugar. Sometimes they’re high, sometimes they’re low. I think that one would make a lot of sense.” While this seemed to the entire project team (e.g., learning experience designers, SMEs, diabetes specialists, etc.) to be an apt metaphor, it lacked sufficient flexibility to capture the diversity we had encountered in participants’ perspectives. However, further elaboration led the design team to the idea of an amusement park metaphor, which was compelling because it was able to capture a wide variety of different aspects of living with diabetes as various attractions. Using this metaphor, we developed different attractions and attraction names for the various content areas related to T1D adherence barriers. For example, a swing attraction entitled The Mood Swing was devised to house content related to identifying, managing, and expressing emotions. A roller coaster entitled The Inhibitor was created for presenting concepts related to inhibition, such as stopping and thinking before acting, and taking control of one’s own behavior. Drawing on
this metaphor, various designs were instantiated in low- and high-fidelity prototypes (Schmidt et al., 2020a, 2020b). Iterative prototyping continued until a complete design proof had been developed. This design proof served as the basis for iterative development in Phase 3 of our learning experience design process (Fig. 8).

**SAM phase 3: iterative development**

In Phase 3, iterative development of Diabetes Journey unfolded across three cycles. First, a design proof was evaluated internally. Recommendations for improvement were then incorporated into an Alpha release. The Alpha release underwent four usability tests with iterative improvements between each testing session. This process led to a Beta release, which underwent two usability tests with iterative improvements between each testing session. After refinements based on findings from the final round of usability testing were incorporated into the design, a final internal quality assurance evaluation was performed and identified design flaws were remedied. The outcome of this was a final Gold release, which was made available for participants to use in a randomized controlled trial (Allen & Sites, 2012).
We provide an example illustration of how our designs evolved across the three cycles in Fig. 9. Fluctuations in blood glucose levels can have significant impact on the mood of someone with T1D. The Mood Swing module is responsive to this in that learners encounter instructions on how to “stop and think” to avoid acting on impulse or assumption. This is accomplished using a six-step process called “STARRS”, which stands for “Stop, Think, Accept, Relax, Reframe, Solve.” This module provides learners with bodily cues to help them become aware of when they need to stop and think, as well as strategies for cognitive reframing and application of problem-solving strategies learned in previous modules. Figure 9 illustrates a scenario in which learners are prompted to reframe a situation so as to avoid making assumptions.
Usability testing procedures

In Phase 3, we conducted a total of six usability testing sessions over three months from April to June, 2020. A semi-structured, task-based, concurrent think-aloud protocol was used, followed by a retrospective interview. This user-centered evaluation method was selected because it elicits real-time feedback from participants along with their emotional responses to testing materials (Albert & Tullis, 2013). The first two sessions were facilitated by a university professor who is an expert usability evaluator, who also directly supervised the facilitation of the remaining usability sessions. The following two sessions were facilitated by a trained PhD-level usability evaluator. The remaining two sessions were facilitated by a trained doctoral student with advanced knowledge in usability evaluation. Each usability testing session lasted between 1.5 and 2 h. A total of seven modules were reviewed, with five participants reviewing one module each and one participant reviewing two modules (which were shorter).

Usability testing participants  A total of six participants were recruited from two institutions: a large Midwestern children’s hospital and a diabetes research center at a large Southeastern university (Table 3). Screening criteria included: (1) a T1D diagnosis > 1 year; (2) between 13 and 17 years old; (3) no significant developmental disorders (e.g., autism spectrum disorder, moderate/severe developmental or intellectual disability); (4) ability to read/speak English; (5) no comorbid medical diagnoses (e.g., cystic fibrosis, asthma) with the exception of endocrine disorders (e.g., Celiac disease, thyroid); and (6) not pregnant. Informed consent and assent forms were completed by parents and children. This project was approved by the institutional review boards at both institutions.

A short technology competence survey was administered with all participants focusing on self-reported ability to use smartphones and previous experience with online learning. Participants reported their abilities using smartphones (expert = 0; experienced = 4; capable = 2, novice = 0), using the Internet (expert = 0; experienced = 3; capable = 3; novice = 0), frequency of smartphone usage (more than once per hour = 4; once per hour = 2; less than once per hour = 0), prior experience with online learning (yes = 6; no = 0), and estimated total time per week spent using the Internet (over 40 = 4; around 40 = 2; between 20 and 40 = 0; less than 20 = 0).

Usability testing data collection  During each session, the facilitator began by greeting the participant and then introduced the purpose of the usability testing with an overview of Dia-

| Table 3  Usability testing participant demographics |
|---------------------------|
| **Descriptor**             | **Details**                      |
| Gender                    | F = 2, M = 4                     |
| Age                       | 13 to 17 yrs, M = 15.5 (SD = 1.67) |
| Ethnicity                 | 5 White/Caucasian, 1 Black/African American |
| English as first language  | All                               |
| Types of devices used to administer insulin | 4 continuous glucose monitor 4 insulin pump 2 insulin injections (e.g., pen, needle) 1 m |
betes Journey. Before reviewing a module, participants answered a set of pre-developed preliminary questions designed to assess technology competence. There were around 10 tasks in each session focusing on a variety of usability issues, both technological and pedagogical. Example technological tasks included going to a specific page using different paths or returning to the previous page. Example pedagogical tasks included reading and interpreting instructions and completing interactive learning activities presented in the module. As participants navigated through the module, they were asked to “think aloud”. All sessions were conducted online using Zoom web conferencing software. Participants shared their screens, webcam video, and audio, which were recorded using Camtasia screen recording software. Five participants completed their session using a laptop computer and one using a smartphone. Upon completion, participants completed the SUS (Brooke, 1986) and a one-item supplemental adjective rating scale assessing the overall user-friendliness (Bangor et al., 2009). Usability testing concluded with a retrospective interview guided by the facilitator.

Field notes were taken by two observers independently during each session and compiled in a spreadsheet once the session was completed. Researchers debriefed to discuss findings, identify usability issues, and plan for next steps. Usability issues identified from each session were rated using Nielsen’s Severity Ratings for Usability Problems (Nielsen, 1994b). This scale ranges from 0 to 4, with 0 representing “I don’t agree that this is a usability problem at all” and 4 representing “Usability catastrophe: imperative to fix this before the product can be released.” For each issue, a solution was proposed and personnel were assigned to fix it. High severity usability issues (rated 3 and 4) were given priority and addressed prior to the next usability session. A total of 285 usability issues were identified from the six testing sessions, of which 262 were addressed. Of the remaining 24
unresolved issues, 13 were not considered usability issues and the rest were related to cosmetic preferences provided by participants (Fig. 10).

Quantitative data analysis

Quantitative data were collected using the SUS, which consists of 10 items with five rating responses from Strongly Agree to Strongly Disagree. It has been widely accepted as a validated and reliable way to evaluate a variety of products and services (Bangor et al., 2008). Participants completed the SUS at the end of each usability testing session. To calculate SUS scores, we subtracted one from all odd (positive-oriented) items and subtracted the original score from five for all even (negative-oriented) items. Next, we multiplied the sum of all scores by 2.5 to normalize them on a scale of 100. According to Lewis and Sauro (2018), a score above 68 indicates that the evaluated system has good usability. Additionally, a one-item supplemental adjective rating scale assessing the overall user-friendliness was administered (Bangor et al., 2009), which states, “Overall, I would rate the user-friendliness of this product as: Worst Imaginable, Awful, Poor, OK, Good, Excellent, or Best Imaginable.”

Qualitative data analysis

Post-usability interview recordings were analyzed and coded by three graduate students. Video analysis was performed in three phases. In the first phase, three trained graduate students individually coded the recorded interview of Participant 1, followed by a discussion among coders to solve discrepancies and identify emerging themes. In the second phase, advised by the lead researcher (a university professor), the three coders referenced two sets of established usability characteristics to guide development of themes, including ISO 9241-11:2018 (ISO, 2018) and ISO/IEC 25010 (ISO/IEC, 2011). Coders referenced emergent coding categories from phase one with these ISO standards, resulting in the following list of codes: (a) appropriateness recognizability, (b) learnability, (c) operability,
(d) user error protection, (e) user interface aesthetics, (f) accessibility, and (g) satisfaction (Table 4). Codes were characterized as either positive or negative under each of these themes. For coder calibration, the three coders and the lead researcher applied the codes to a sample of the full data set together, discussed discrepancies, and clarified misunderstandings. In the third phase of coding, each of the three coders coded the full data set. Regular discussions were held to clarify understanding of how to apply codes and minimize coder drift. Coders discussed and remedied any discrepancies. ISO definitions for coding themes were referenced when coders found it difficult to reach agreement. Following this coding process, inter-rater reliability was assessed. Analysis was conducted in R (R Core Team, 2017) and Fleiss’ Kappa reliability estimates were computed using the package irr (Gamer et al., 2019). The resulting Fleiss’ Kappa value (κ = 0.683) suggested substantial agreement among coders (Altman, 1990).

Findings

Quantitative findings

SUS and adjectival rating scale data are reported in Table 5. The mean SUS rating was 86.25 (sd = 9.19), indicating high learner satisfaction and overall perceived usability. This quantitative measure corresponds with qualitative findings (detailed in the following section). The first four usability testing sessions were conducted using the alpha release and the last two sessions were conducted with the beta release. Ideally, responses on odd numbered questions should indicate an upward trend of scores while those on even numbered questions showing a downward trend. In the current dataset, this assumption holds except for beta release participants’ responses on items 1, 5 and 10. For items 5 and 10, we surmise this could be attributed to varying technology competencies or potential misunderstanding of SUS items. For the discrepancy with item 1, this could be due to the substantial improvements we made between Alpha and Beta releases to the introductory module, which included not only an introduction to the program but also detailed instructions of how to use it.

Qualitative findings

In total, 180 data units were coded. No accessibility codes were applied. Statements such as “I don’t know” or “I don’t think I have any questions” were coded as not applicable (16% of the full data set). One data unit fell into the theme: user error protection with a positive result (“It’s not like other websites where some stuff is unresponsive…”). The remaining themes contained both positive results (which revealed features that promoted usability), and negative results (which unveiled usability problems).

Four themes received more positive results than negative: appropriateness recognizability (32 positive vs. 3 negative), learnability (16 vs. 4), user interface aesthetics (17 vs. 9), and satisfaction (50 vs. 2). Operability was coded positively in 10 instances and negatively in eight. Examples of designs promoting appropriateness recognizability included: meeting learner’s perceived purpose (“It did what it was supposed to do”), appropriate content (“No information was out of place”), and fitting learners’ needs (“It just gave you new techniques to use”). Examples of designs promoting learnability appeared to represent both technological learnability, which is related to learning
### Table 5  Individual SUS scores and aggregate SUS score

| Item                                                                 | Participant | Mean | Min | Max | SD  |
|----------------------------------------------------------------------|-------------|------|-----|-----|-----|
| (1) I think that I would like to use this module frequently          | P1 P2 P3 P4 P5 P6 | 3.83 | 3   | 5   | 0.75 |
| (2) I found the module unnecessarily complex                         |             | 1.17 | 1   | 2   | 0.41 |
| (3) I thought the module was easy to use                             |             | 4.67 | 4   | 5   | 0.52 |
| (4) I think that I would need the support of somebody to be able to use this module |             | 1.33 | 1   | 2   | 0.52 |
| (5) I found the various functions in this module were well integrated|             | 4.33 | 3   | 5   | 0.82 |
| (6) I thought there was too much inconsistency in this module        |             | 1.17 | 1   | 2   | 0.41 |
| (7) I would imagine that most people would learn to use this module very quickly |             | 4.50 | 4   | 5   | 0.55 |
| (8) I found the module very awkward to use                          |             | 1.50 | 1   | 2   | 0.55 |
| (9) I felt very confident using the module                          |             | 4.33 | 4   | 5   | 0.52 |
| (10) I needed to learn a lot of things before I could start using this module |             | 2.00 | 1   | 3   | 0.89 |
| Overall, I would rate the user-friendliness of this module as:       |             | 5.83 | 5   | 6   | 0.41 |
| SUS aggregate score                                                  | 86.25 77.5 95 100 80 80 | 9.19 | 80  | 85  | 100  |
to use the intervention/product (e.g., “it was just straight to the point” in response to learner’s experience with the module being tested, “It was simple and that made it easier to understand” in response to learner’s feeling about using the technology) and pedagogical learnability, which is related to meeting learners’ perceived learning goals and/or learning outcomes (e.g., “I thought it was really informational. I learned a few things”, “It was nice it used examples and I could relate to the examples”, and “It’s very forward and easy to understand…” in response to fit with what the participant wanted to learn). Examples of positive user interface aesthetics include interface layout design (“I liked the layout of it”), the design of the pedagogical agents (e.g., “I liked the cartoon lady and how she was a teenager talking to you”, “I liked how there were little people at the top”), progress bar (“My progress reminds me of what I have done in the past”), and the amusement park design (“The map is unique but it is fun and good, and I like it”). Examples of participants’ overall satisfaction include comments such as “I don’t think there was anything more you [the designers] could do”, “It was pretty easy to use”, and “it was a very good experience”. Examples of features that promoted operability include interactive controls (“the buttons are very clear on what it is gonna show you”), appropriateness for device type (e.g., for smartphones “it seemed like it would be easy to use too”, “It was pretty easy to use on the Mac”), navigation (“It’s not hard to navigate through”), and interactive features (“I like the little flash cards where you could click on it and it would flip.”). The positive results from post-usability interviews were largely in agreement with positive SUS results reported in the section above.

Factors that detracted from usability were also identified. Examples of appropriateness recognizability issues included relatedness to learners’ needs (“the problem solving was useful, but the problem itself wasn’t a problem I face as much”), sensitive to learners’ prior knowledge (“It talks about... which I kind of knew about already”). An example of learnability issue was related to making a personal connection (e.g., “it would make me feel more connected if it asked more personal questions”, “Like using Sam as [an] example for what burnout is like and how to make it better going through the 3 steps”). Examples of user interface aesthetics issues included color (“I personally don’t like white... felt I was reading an article”), images (“I would [like to] add more imagery”), pedagogical agent avatar (“More characters. We just have Coach Frank and Maxine”). Examples of operability issues included a need for further guidance on how to use the system (e.g., “There was one point where it didn’t really explain what you needed to do”), and disfavor with locked modules (“it would be helpful if you could access certain sections”). Examples of satisfaction issues included enhancing the trustworthiness of the product (“it would make me [feel] more comfortable if it would allow me to know this isn’t just some website made by some person I don’t know”) and syntax (“in messaging there was spelling errors like no capitalization”).

Design revisions

Design revisions were made following each usability test. Taken together, findings from the SUS and post-usability interviews suggest that Diabetes Journey as an intervention for adolescents with T1D was appropriate in terms of learning needs, learnable in regard to instructional content as well as the program itself, and satisfying as to the design of user interface aesthetics and overall learner experience. Participant feedback from iterative usability testing not only enabled the design team to improve the design, but also
Table 6  Select features that promoted a positive learner experience with diabetes journey

| Domain                        | Participant observations                                                                 | Specific examples                                                                 |
|-------------------------------|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Interactive components        | Participants indicated that they enjoyed using the interactive components                | • Self-paced slideshows                                                          |
|                               |                                                                                          | • Flip cards                                                                    |
|                               |                                                                                          | • Embedded Articulate Storyline objects                                           |
| Consistency in content and message design | Participants noticed that text and multimedia content was presented in a uniform and predictable manner across pages and modules | • Use of flip cards to introduce new concepts and definitions                     |
|                               |                                                                                          | • Use of coaches to introduce each page and activity                             |
|                               |                                                                                          | • Different message types (e.g., system, pedagogical) used consistent design patterns |
| Consistency in interaction design | Participants stated that the system exhibited expected behavior                         | • Multimedia elements were intuitive and straightforward                         |
|                               |                                                                                          | • Notification elements invited behaviors and hinted at outcomes (e.g., “Select ‘Start Here’ to begin!”) |
| Variety                       | Participants remarked on the variety in content, presentation, and interactive activities across modules and pages | • Various forms of activities, such as role-plays, games, knowledge checks, etc |
|                               |                                                                                          | • Instructional content in a variety of media formats (e.g., video, games, etc.) |
|                               |                                                                                          | • Different coaches provided variety in prompting and feedback                   |
| User interface aesthetic design | Participants liked aesthetic elements such as colors, coach avatars, page layouts, and amusement park theme | • Coach “Frank” and more knowledgeable peer “Maxine” directly address learners using everyday language |
|                               |                                                                                          | • Modules are “attractions,” corresponding to those commonly found at real-world amusement parks |
suggested the three-phase learning experience design resulted in a highly acceptable, socio-culturally sensitive, and relevant product for the target population.

Qualitative analysis uncovered themes that fell into two categories: (1) features that promoted usability (Table 6) and (2) features that detracted from usability (Table 7). Features that promoted usability included: (1) interactive components, (2) consistency in content design, (3) consistency in interaction design, (4) variety, and (5) user interface aesthetics design. For example, one adolescent participant experiencing the module “Memory Monorail” expressed appreciation of the flip cards activity as well as the self-paced presentation on page “Mnemonic Devices”. This participant also appreciated the variety in designs across the program, stating: “It [multimedia activities] wasn’t the same on every page”. To be sure, this design principle providing opportunities for varied forms of interaction was appreciated by many participants (“Not everything stayed the same”, “I liked the different things, the presentation and the flash cards [flip cards]”). Additionally, this participant liked the instructional examples provided, was able to relate to them, and was able to use them to come up with his own examples.

Usability problems identified by participants were mostly related to (1) navigation design, (2) features of interactive activities, and (3) pedagogical design of content. For instance, one participant was not able to return to the homepage while he was in a module, expressing confusion with the “Home” button. Because the team purposefully designed the homepage as an amusement park map, it is reasonable that the participant did not associate “Home” with something that represented a map. Subsequently, the team changed the name of the button to “Map,” which was later confirmed by other participants as effective. An example of a problem that hampered pedagogical usability was caused by an interactive, non-linear, branching activity. During usability testing, the participant failed to complete the task due to unclear instructions and confusing functionality (“This page is kind of confusing, I don’t know what to do”). During the debrief session, the team agreed on a complete redesign of the activity using a different development tool with more intuitive features. The new technology enabled functionalities that allowed for changing the status of buttons (e.g., invisible, locked, unlocked, etc.), which was later remarked upon by different participants as a feature that promoted pedagogical usability. Based on feedback from multiple participants, the team populated the Ticket Booth introduction module with an overview of the program that introduced the coaches, demonstrated navigation, allowed learners to practice sample interactive activities, and provided contextualized feedback.

**Discussion**

T1D is a chronic condition requiring intense day-to-day management. Effective T1D treatment seeks to achieve nearly normal blood glucose levels via a complex constellation of medical and behavioral provisions; however, difficulties with T1D treatment self-management in adolescents can result in suboptimal glucose levels and potentially lead to both acute and long-term complications. T1D self-management tasks for adolescents are a particular challenge, in part due to stress/burnout and executive dysfunction related to time pressure and planning experienced during this developmental stage. However, reports of mHealth interventions aimed at improving these two factors together are limited in the research (i.e. Miller et al., 2020) or clinical practice.
Table 7 Select features that detracted from the learner experience of diabetes journey

| Domain                     | Participant observations                                                                 | Design improvements                                                                                     |
|----------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Navigation design          | • Difficulty returning to the homepage                                                     | • Used more descriptive labels (i.e., instead of “Home”, used “Map”)                                     |
|                            | • Participants expressed confusion due to unclear instructions                             | • Added clear and consistent system and pedagogical notifications across modules and pages                |
|                            | Features of interactive activities                                                         |                                                                                                          |
|                            | • Some buttons in interactive presentations were superfluous and were confused with the “Exit” button | • Removed of superfluous buttons                                                                        |
|                            | • One participant unable to complete a task due to interaction flaws in underlying software |                                                                                                          |
| Pedagogical design of content | • Participants did not understand the roles of Coach Frank and Maxine                     | • Redesigned activity using a different software tool and replaced problematic activity                   |
|                            | • One participant suggested using real names in examples to build connection with the target population | • Added section in which Coach Frank and Maxine introduce themselves at the “Ticket Booth”                |
|                            |                                                                                           | • Real names (e.g., Sam, Alisha, Elias) and photographs were incorporated in instructional examples         |
Therefore, behaviorally-focused interventions for adolescents with T1D seeking to promote these psychosocial factors are in urgent demand. Diabetes Journey seeks to address these needs by helping adolescents with T1D learn to enhance and utilize their self-management skills related to stress/burnout and executive dysfunction. Diabetes Journey adopted an LXD approach to provide target learners with a personalized learning experience and actionable knowledge through gamified elements and an interactive mobile interface. This article elaborates the design, development, and evaluation of Diabetes Journey from the perspective of LXD and multiple learner-centered methods to promote relevance and learner engagement.

Limitations

Although findings from the current study are largely positive, a number of limitations should be considered. First, due to the impact of COVID-19 pandemic, planned on-site usability testing had to be moved into a fully online format. This limited the opportunity to collect data such as eye tracking or biometrics. Remote technical issues and troubleshooting also could have influenced usability testing. We suggest future researchers consider collecting and triangulating more types of data if on-site usability testing is feasible. In addition, participants in the current study may not be representative of the whole population of adolescents with diabetes in terms of ethnicity and technology/online learning proficiency. Five out of the six participants were white and all of them were technologically proficient and had online learning experience. Future research should consider collecting data with a more diverse group of participants.

Implications for human-centered mHealth design

Although patient-centered design increasingly is gaining attention in healthcare contexts, a variety of limitations have been noted in the mHealth for diabetes management literature. These include a lack of effective education and self-management principles, provision of personalized and actionable knowledge, usability evaluation, theoretical alignment with technology-based learning principles, and engagement factors (e.g., Albanese-O’Neill et al., 2019; Arsand et al., 2012; Goyal et al., 2016; Whittimore et al., 2010, 2018; Yu et al., 2014). The findings from the current study represent preliminary work towards addressing these limitations using patient-centered methods. First, in response to the limited examples of mHealth interventions that apply learning theory and principles in the development process, our work serves as an exemplar of how theoretical perspectives such as situativity theory can be used to inform and guide methods and processes. Second, in response to critiques by Whittemore et al. (2010), our work illustrates how we intentionally and systematically developed theoretical- and usage-inspired design principles to guide our design process (Table 2). Future mHealth designers and researchers could benefit from using the multidimensional framework proposed by Kali (2006) to characterize design principles along a continuum of abstract to specific, as this allows for distillation of theoretical knowledge (i.e., meta principles) into more concrete, actionable concepts (i.e., specific principles). Indeed, such an approach holds promise for avoiding mHealth intervention designs based primarily on intuition, experience, and clinical judgment. This is not to discount the contributions of clinical intuition, experience, and clinical judgment, as they are needed to ground theory. However, we posit that theoretical, methodological, and design perspectives such as those from learning experience design can serve to balance
the multifaceted tapestry of mHealth design. Finally, regarding the reported paucity of systematic methods to validate mHealth designs, our work illustrates a multimodal approach that incorporates both qualitative (e.g., cognitive walkthrough) and quantitative (e.g., SUS) measures during the evaluation phase, leading to more objective and reliable findings (Lu et al., 2022). Additionally, the iterative development process with multiple participants (i.e., Alpha release, Beta release) can provide mHealth designers with opportunities for not only remedying design flaws, but also validating refinements with different patients.

**Extending sociotechnical-pedagogical usability**

STP heuristics were used to guide the design, development, and evaluation of Diabetes Journey because they provide a human-centered, multidimensional, ecological lens through which to design and evaluate learning technologies (Jahnke et al., 2020). However, applying these heuristics within our specific mHealth design context (which is single-user) revealed a limitation in how the social dimension is characterized within the STP framework. More specifically, sociotechnical-pedagogical usability presumes that learners will collaborate or meet in an online space (for example, using discussion boards or synchronous web conferencing). As a result, factors related to the social dimension are fairly narrow, considering, for example, social presence and group activities. These are factors that are not necessarily present in single-user applications; however, this does not imply that social considerations are not important in single-user applications.

On this basis, we propose a reconceptualization of the social dimension of STP usability not to focus only on aspects of social presence and group activities (as these are not germane to single-user design contexts), but instead to adopt a broader conception of “social” to include the shared and individual sociocultural contexts that shape sensemaking. This approach provides opportunities for designers to consider how the lived experience of patients could inform design. This perspective draws from Gray’s (2020) call for design approaches “that may resonate more with the lived experience—socially, culturally, and experientially—of particular groups of humans that wish to learn” (p. 10). Sociocultural usability is an area that, to our knowledge, remains unexplored in the fields of learning design and instructional design, and therefore represents a direction for future research.

**Conclusion**

The current study sought to address three research questions. The first focused on how participants characterized the usability of Diabetes Journey. Qualitative and quantitative findings from user testing suggest that the program was user-friendly (e.g., “it was easy to use...”), learnable (e.g. “I’ve always needed to learn how to organize my stuff better”), and relevant (e.g., “I could relate to the examples”) for adolescents with T1D. In particular, participants recognized the program meeting their perceived learning goals (e.g., “It did what it was supposed to do”, “the problem solving was useful”), which are key contributors to motivation and engagement in terms of program utilization. The second research question centered around the nature of learner experience with Diabetes Journey. On the basis of empathy methods and borrowing from Jahnke et al. (2021) STP framework, we developed a series of sociotechnical-pedagogical design principles to guide the design of Diabetes Journey. User testing suggests participants had predominantly positive experiences when experiencing the resulting learning designs. For example, many participants expressed appreciation of having Coach Frank and Peer Maxine accompanying them in their journey
and some wished more characters could be involved. Additionally, changes in learners’ responses from pre- to post-surveys in each learning module objectively reflected substantial recognition of our designs. Research question three sought to identify ways in which the learner experience and usability of Diabetes Journey might be improved. Improvements were iterative and ongoing. Of 285 usability issues, 262 were addressed. Broader issues relating to navigation design, features of interactive activities, and the pedagogical design of content were addressed more holistically. Taken together, findings suggest that Diabetes Journey is highly usable, relevant to identified needs, and engaging for the unique target population of adolescents with T1D.

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**Declarations**

**Conflict of interest** The authors declare that they have no conflict of interest.

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Jessica C. Kichler, CDCES, Ph.D., C.Psych, is a Clinical and Health Psychologist, Certified Diabetes Care and Education Specialist, and an Associate Professor in the Department of Psychology at the University of Windsor. She specializes in pediatric health research exploring psychosocial adjustment and coping with chronic medical conditions, especially type 1 diabetes in youth and families. She is also involved in clinical intervention research that helps improve diabetes self-management and education practices and appreciates working collaboratively in interdisciplinary settings. In addition, she is interested in how to best support college-aged students with type 1 diabetes successfully transition to young adulthood.

Sarah D. Corathers is an endocrinologist in Cincinnati, Ohio and is affiliated with multiple hospitals in the area, including Cincinnati Children’s Hospital Medical Center and University of Cincinnati Medical Center. Based on dual training in pediatric and adult endocrinology, her interests and experience are in the care of adolescents and adults with endocrine conditions across the lifespan. The intersection of her research and clinical interests includes psychosocial aspects of diabetes management, mechanisms to promote successful transition between adult and pediatric healthcare, and health system-based interventions to improve care delivery and outcomes.
Laura M. Jacobsen is an Assistant Professor and Pediatric Endocrinologist at the University of Florida. She is assistant program director for the pediatric endocrinology fellowship program. As a physician scientist, Dr. Jacobsen cares for patients and families with diabetes and endocrine disorders in addition to performing quality improvement and translational research in the field of type 1 diabetes. Dr. Jacobsen has a focus in understanding the natural history of type 1 diabetes and immunotherapies to interdict in this disease process.

Anastasia Albanese-O’Neill, PhD, APRN/PNP-BC, CDCES, transitioned to a career in diabetes care, education, and research in 2008, and since that time has committed her professional life to improving the lives of people with diabetes. She is currently in private practice, where she serves as a key opinion leader on national committees and working groups, is an advisor to companies and non-profit organizations, and trains people with diabetes to use automated insulin delivery systems. She created and maintains a diabetes education website, T1DToolkit.org, that is available at no cost in the public domain.

Laura Smith, PhD, CDE, is a professor of pediatrics, a pediatric psychologist, and certified diabetes educator at Cincinnati Children’s Hospital Medical Center and the University of Cincinnati. Dr. Smith provides clinical care and conducts research in the area of pediatric type 1 diabetes. Her research focuses on disordered eating and type 1 diabetes, how family interactions impact diabetes management, and the psychological impact of being genetically at-risk for type 1 diabetes.

Sarah Westen, Ph.D., is a licensed psychologist and Clinical Assistant Professor in the Department of Clinical and Health Psychology at the University of Florida. Dr. Westen is currently the Director of Diabetes Behavioral Medicine and Psychology at UF Health, a Board Member on the American Diabetes Association’s Youth Strategies Committee, and a Board Member on the JDRF Psychosocial Advisory Committee. Dr. Westen is former Chair of the American Psychological Association’s Special Interest Group in Diabetes, and a former JDRF National Psychology Fellowship recipient. Clinically, Dr. Westen is interested in the biopsychosocial aspects of chronic illness throughout the lifespan. Her patient-oriented clinical research focuses on factors affecting adherence to medical treatment regimens. Dr. Westen is additionally interested in improving care in underserved communities for individuals living with diabetes.

Ana M. Gutierrez-Colina is an assistant professor and licensed clinical psychologist at National Jewish Health where she works with youth with respiratory and immune conditions. Her research is focused on medication adherence and self-management, as well as adjustment and quality of life in chronic illness.

Leah Heckaman holds a Master of Science degree in Health Education: Public and Community Health from the University of Cincinnati. She started her work at Cincinnati Children’s Hospital Medical Center in 2019 and is a Clinical Research Coordinator III in Dr. Avani Modi’s lab. Her research interests include adherence in pediatric type 1 and type 2 diabetes and Health-Related Quality of Life.

Sara E. Wetter is a graduate student under the mentorship of Dr. Kimberly Driscoll in the University of Florida’s Clinical & Health Psychology doctoral program. She graduated from Anderson University with a B.A. in Psychology in 2016 and earned an M.A in Clinical Psychology from the University of Dayton in 2018. After graduation, she worked as a clinical research coordinator in Cincinnati Children’s Hospital Medical Center’s Center for Adherence and Self-Management under the supervision of Dr. Avani Modí; in this role, she worked on NIH-funded clinical trials aimed at improving medication adherence in children and adolescents with epilepsy. Sara is interested in provider bias and its impact on care and health outcomes in youth and young adults with Type 1 Diabetes.

Kimberly A. Driscoll, Ph.D., is an associate professor and a licensed clinical psychologist in the Department of Clinical and Health Psychology at the University of Florida. She also holds an adjoint appointment as Associate Professor of Pediatrics in the University of Florida College of Medicine. Dr. Driscoll is also the Director of Behavioral Science Research in the University of Florida Diabetes Institute. Her research focuses on the delivery of behavioral interventions to improve adherence and health outcomes, with a focus on using technology to optimize adherence and health outcomes in type 1 diabetes. Dr. Driscoll has received NIH funding continuously since 2012. Dr. Driscoll earned her Ph.D. in clinical psychology from Florida State University. She completed her residency at Children’s Hospital and Clinics of Minnesota and her fellowship training at Cincinnati Children’s Hospital Medical Center where she specialized in working with children with cystic fibrosis and their families.

Avani Modi, PhD, is Professor in Behavioral Medicine and Clinical Psychology at Cincinnati Children’s Hospital Medical Center and the University of Cincinnati-College of Medicine. She is the Director of the
Center for Adherence and Self-Management at Cincinnati Children’s Hospital Medical Center. Dr. Modi has several grants from the National Institutes of Health grants focused on adherence for children and adolescents with epilepsy. Dr. Modi has over 150 peer-reviewed publications and book chapters, as well as a book focused on adherence and self-management. Her research focuses on mobile health interventions to improve adherence to anti-seizure medications and quality of life in youth with epilepsy. She has received numerous national and local honors and awards and is an international expert in adherence and self-management.

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