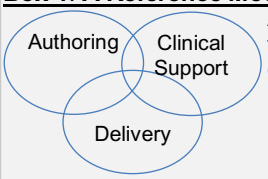
**Project Summary**

Digital Health (DH) research, notably in mobile health (mHealth) apps, is expanding in volume and influence; there are more apps across more clinical contexts than ever before. Significant challenges in exist; the ability to conduct research at the speed of technological change, and sustaining effectiveness of DH technology over long periods. Recent ideas such as multidisciplinary processes (like Agile Science[1]), and personalized and adaptive mHealth[2,3,4] are attempting to move the field to address these challenges. This research project proposes the development of a new model for DH interventions (DHIs) with a focus on technology, to address a significant gap in multidisciplinary research methods.

DHIs often rely on theoretical foundations in human behavior change (HBC). Several families of HBC theories exist, but corresponding theories explaining the effectiveness of DHI implementations for HBC are few and far between. Instead, much of the published literature attempts to derive technology effectiveness directly from HBC theory and ad hoc mappings to information technology machinery. A notable exception is Health Behavior Change Support Systems (HBCSS) theory (Oinas-Kukkonen[5]), which models HBC types (*C*ompliance, *B*ehavior, and *A*ttitude) derived from Persuasive Systems Design originated by B.J. Fogg (Fogg Behavior Model[6]). However, even HBCSS lacks a reference architecture or language for describing DH technology that can effectively connect HBC science to DH machinery. In essence, we are in a continuous cycle of repeating in technology that may sound different but in fact is not, being unable to break this cycle due to the lack of higher order tools for expressing the nature of DH interventions. Constructs are needed that are independent of specific technology platforms (smartphones, game platforms, voice services, IoT, smart homes, etc.) yet can support expressions of how such constructs impact the cost and value of DHIs. This project will address this gap by defining a reference model and language for DHIs, initially scoped to mHealth solutions (this is a first step, the approach will not limit future extensions to other forms of DH). Box 1 outlines reference model concepts while Box 2 outlines preliminary language constructs.

**Box 1: A Reference Model for DH Systems**




A *Delivery* system is responsible for receiving input from users, devices or other systems (*how*), making intelligent decisions *(why)* on *who* gets delivered *what* content, and *when* & *where* it is rendered to a consumer

| *Authoring* | *Delivery* | *Clinical Support* |
|---|---|---|
| Content | Intervention rendering | Decision support |
| Packaging | Input processing | Monitoring |
| Metadata | Intelligent delivery | Management |

**Box 2: An Event-based Language for DHI (sketch)**

$L=<E,O,S_O,S_E,R>$ is a language where $E=<e_1,e_2,\ldots,e_n>$ is a sequence of events, ($E^C$ a subsequence of $E$ filtered by condition $C$), $O=\{o_1,o_2,\ldots,o_n\}$ is a typed set of objects $S^O=\{s^o_1,s^o_2,\ldots,s^o_k\}$ is a set of object states, $S^E=\{s^e_1,s^e_2,\ldots,s^e_m\}$ is a set of event states, and $R=\{r_1,r_2,\ldots,r_j\}$ is a set of Relations s.t. r($E^C$,$S^O$,$S^E$): → <$E^C$,$S^O$,$S^E$>. $E_i$ captures events, initiated by objects or external. $O_i$ are elements of interest (people, devices), in the domain. Sets $S_X$ define state models for events and objects (transitions are in $R$). $R$ maps event sequences based on object end event states to new events and transitions of new states and objects. *Examples:* an event could be a phone notification, and an event subsequence a sequence of subsequent notifications in a DHI. An object may be role-based (patient, caregiver) or a device (phone, sensor). Object and event states depend on the element, but could be {*created,pending,delivered,acted_on,archived*} for a micro-intervention event. A relation might be notification (*event)* acted_on (*event state*) by Susie (*parent caregiver - object*) while worried about Jimmy (*patient – object).*
Clearly a formal and complete treatment is needed, but many examples may be expressed with these simple constructs, derived from computer science languages in domains such as process modeling, discrete event simulation, and state-based modeling.

The proposed research methodology for the project calls for two phases. In the first phase, a suite of existing mHealth interventions described in the literature and available as open science will be used as a design portfolio. These systems will be expressed in specific terms under the reference model, and the nature of the intervention expressed under the language. The PI has informally done this for a set of locally-developed mHealth apps. During this process refinement of the model will occur. In the second phase, 3 new mHealth DHIs will be constructed using this underlying model under a process of personal ethnography, to evaluate the utility of using these tools for design, not just retroactive description.

*Intellectual Merit of the Proposed Research*: The intellectual merit of this research is the specification of a reference model and meta-language for defining, describing and evaluating DHIs. A reference model and language will transform the field in several ways. First, it will provide a common vocabulary for describing mHealth interventions, replacing inconsistent technical jargon. Second, it will impact the expression of design, development, and evaluation processes in interventions, providing a more expressive manner for defining research aims and multidisciplinary evaluation. Third, it will assist with anticipating future technological innovations and potential impacts on DHIs. While this last advancement is very ambitious, the field needs to understand how technological mechanisms can be defined, described, and compared from a common frame of reference to break the slow and repetitive cycle of "shiny new bauble" is not really "new".

*Broader Impacts of the Proposed Research* Society has seen an explosion of digital interventions across many walks of life, none more important than health. Digital health innovation through pervasive commercial off-the-shelf technology disrupts traditional delivery mechanisms through speed, accessibility, and granular detail. Individuals can generate and access data, conduct finer-grained interventions, and do it faster and more frequently than ever before. Further, individuals are empowered to take control of their healthcare, which has significant personal and economic upside but also risk (self-diagnosis and treatment, security and privacy, stigma, etc.). The technology focus has been on more powerful algorithms and systems, while underlying theory that addresses clinical outcomes has not been unified with adequate expressions of the technology. The effect is repeated studies of mHealth technology "X" (SMS, notifications, feature phones, smartphones, gamified elements, etc.) in clinical context "Y" where the impact unsurprisingly does not change if one understands the commonalities and differences of the Digital Health mechanisms. The proposed research will present a reference systems framework and meta-language to describe DHIs so research inefficiencies may be better addressed by the community.

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[2] Nahum-Shani, I., Smith, S. N., Spring, B. J., Collins, L. M., Witkiewitz, K., Tewari, A., & Murphy, S. A. (2018). Just-in-time adaptive interventions (JITAIs) in mobile health: Key components and design principles for ongoing health behavior support. Annals of Behavioral Medicine, 52(6), 446–462.
[3] Spruijt-Metz, D., & Nilsen, W. J. (2014). Dynamic Models of Behavior for Just-in-Time Adaptive Interventions. https://doi.org/10.1109/MPRV.2014.46
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[5] Oinas-Kukkonen, H. (2013). A foundation for the study of behavior change support systems. Personal and Ubiquitous Computing, 17(6), 1223–1235.
[6] Fogg, B. (2009). A behavior model for persuasive design. ACM International Conference Proceeding Series, 350.