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Modern technologies take learning outside of the classroom environments and enable learning in the context of individuals' daily lives. My research is inspired by **gamified ubiquitous learning** in which users can access technologies for facilitating learning from anywhere, and when needed throughout their lifetime in a fun and engaging way. In particular, I investigate learning content that is not well covered in traditional learning environments, such as **health and wellness** information. My work explores the delivery of such learning content through **social and playful computing technologies** that are used at a large scale. I plan to build upon the current research I do as a post-doctoral researcher by identifying ways to leverage increasingly popular self-monitoring technologies to help high-risk and underserved individuals learn from their everyday experiences and experiences of others in a scalable, light-weight, and playful manner.

Two of the three key dimensions of United Nation's Human Development Index for societal wellbeing are health and knowledge. My vision is to leverage technology at the intersection of healthy living and learning to build better platforms that incorporate educational tools and games for low-resourced and underserved populations. Despite the wide availability of mHealth technologies for such populations, they continue to suffer from under-utilization and high attrition. I use these platforms to establish and test the theoretical foundations of motivation and engagement in learning technologies. To address the difficulty in sustaining users' engagement for health promotion and education, game-based motivational strategies and gamification features have been adopted to many health apps. In my work, I draw on my background in teaching in STEM (K-16), Cognitive Studies in Education (MA), Instructional Technology and Media (EdD), and Biomedical Informatics (Post-doc) to design educationally-oriented and playfully inspired interfaces that lead to engagement and life-long learning. Through my various projects, I have led interdisciplinary teams to establish project directions and formulate research questions in collaborative environments, mentored undergraduate, Master's, and doctoral students on different research projects, and delivered results to different communities through publications, presentations, and tools such as games and apps.

Persuasively Framed Messages Embedded in a Digital Game

In my dissertation, I investigated the impact of framing on efficacy of messages embedded in game environments to promote nutritional literacy and healthy nutritional choices. However, I took a rather unconventional, subversive approach to promote healthy choices. I hypothesized that rather than reminding players of familiar healthy choices, like most contemporary games for health, rewarding them for making unhealthy choices in a game environment could help inoculate them against these behaviors in real life. I showed that such unconventional **subversive framing** helped positively affect learning evidenced through players' behavioral perception, intention, and choices [Hwang '16;'17]. In the course of this work, I developed and implemented a web-based digital game, "Monster Appetite", and embedded **loss-framed** messages that highlighted the negative impact of unhealthy snacking. The game also gave visual feedback on players' choices of high or low calorie snacks embodied through a growing monster avatar [Hwang '12;'13;'14;'16]. From this project, I saw powerful effects of unconventionally framed, persuasive health messages and digital representations of these messages (e.g., avatars) that aid in the **education and promotion of healthy behaviors** [Hwang '18b]. While Monster Appetite had a positive impact on learning, it focused solely on individuals' learning and could not leverage the ability of social interaction to increase learning factors, such as motivation and peer feedback. A natural extension to my previous work on Monster Appetite was to integrate a social component to the activity, which became the focus on my following projects.

Learning from Socially Generated Data for Nutritional Assessment

In order to leverage social learning in settings such as Monster Appetite, my postdoctoral work at the Department of Biomedical Informatics has focused on designing and developing interactive informatics solutions that deliver health content in social settings in an effective and motivationally intriguing way. In one of my first projects, I investigated opportunities to leverage social technologies to promote nutritional learning. Specifically, I tested the effectiveness of a novel '**learning-by-example**' paradigm for meal assessment on user-generated meal photographs compared to a standard diabetes education strategy for nutritional evaluation. In the 'learning-by-example' paradigm, individuals compare their own meals to other users' meal photographs with known nutritional composition. They then use these meals submitted by others as benchmarks for estimating nutrition in their own meal. The traditional strategy requires individuals to assess meals by decomposing and estimating portion sizes

and macronutrient content in a stepwise procedure. In a between subjects experiment conducted with Amazon Mechanical Turk, both strategies were effective. However, the novel 'learning-by-example' strategy had significantly greater influence on **learning and knowledge transfer**, while the traditional strategy showed greater accuracy in nutritional estimation while the strategy was in use in real-time.

Based on this discovery, I started investigating applicable computational methods for future research opportunities so that more users in their daily lives can enrich their nutritional learning from socially-generated data. Going forward, my goals include merging the 'learning-by-example' approach with data science to address the issue of learning at scale at a low cost while keeping high user engagement. In order to accomplish this, I have taken the first steps of designing a crowdsourced, data-driven, mobile user-interface leveraging theories from learning sciences and gamification. This mobile interface has a number of benefits and opportunities to create unique and optimal learning experiences. First, users can nutritionally evaluate their real-life meal photos on demand by comparing them to other users' meals that have been evaluated socially. Second, social computing platforms can encourage the culture of 'learning together' through helping users take ownership of their evaluated meal photos by sharing them with the community, receiving feedback from peers and points on those assessments, and developing a reputation and status for nutritional assessment. However, all these advantages hinge upon the assumption that the average user is somewhat equipped at estimating nutrition from a meal photo.

A key component in educating users with skills to estimate nutrition from a meal photo is a large database of correct learning material. The current state-of-the-art is to rely on expert dieticians to provide their expert estimate of nutrition in meals, yet this approach is labor intensive and expensive. In contrast, we plan to leverage crowdsourcing to bring educational content generation to a new scale. However, the learning material must be correct if users are to learn correctly, and this is especially true in the health space. Because average users will tend to make imprecise comparison estimates from meal photos, we need to build an algorithm that can optimize the crowd's selection of closest match among alternatives, which involves a correct ordering with an error tolerance. I researched several stochastic search algorithms with an error tolerance such as a type of noisy binary search. Building algorithms that both deliver effective and correct information to users is a challenge from both a technical and social perspective. First, managing the user-generated data in an easily retrievable and meaningful way is crucial and challenging. Second, in the case that our algorithm coalesces the crowd data to an incorrect estimation, there needs to be steps for correction in the data, inference, and/or learning. Therefore, while there are many benefits to **data-driven technologies**, a safety measure for accurate interpretation of aggregate data is important for meaningful inferences. My research will investigate strategies in addressing these challenges intelligently at scale. While the aforementioned challenges are focused on data sorting and interpretation, in other projects we identified new challenges as we took our projects out in the real world setting: collecting data from disengaged users to make meaningful, personalized health recommendations. The following describes such projects.

The Cold Start Problem in Data-Driven Health Interventions

As part of a large, Robert Wood Johnson Foundation funded self-monitoring intervention, I am collaborating with an interdisciplinary team at Columbia University on a custom-designed smartphone application to be used with the Washington Heights underserved immigrant population with type 2 diabetes in New York City. As part of this multi-prong project, we are continuously modifying and updating our strategies to encourage sustained engagement in our target population. Specifically, we use a sequential, multiple assignment, randomized trials design approach where we switch participants in different conditions that provide different feedback for dietary self-monitoring activities (e.g., dietitian feedback, no feedback, blood glucose prediction feedback). I am planning a second study in which we are devising an on demand, personalized, decision support system for dietary management for a low health-literacy population. This study will provide the personalized decision support through data provided by the users such as their meals and blood glucose responses to those meals. This type of research is particularly challenging, as we have to deal with the **cold start problem** (i.e., little to no initial data of new users) but still find ways to provide recommendations for dietary improvement drawn from user data.

In another study, we directly tackle this cold start problem by drawing lessons from traditional recommender systems investigations. Our lab recently introduced a research app for personal forecasting of blood glucose levels for individuals with diabetes and made this app available through app stores (Apple App and Google Play stores). GlucOracle provides individuals with personalized forecasts for post-meal blood glucose (BG) levels,

given their pre-meal BG and nutrition in the planned meal. Similar to other health apps, GlucOracle faces challenges with the cold start problem of providing value to users who have collected little personal data. I led a team to address this issue by testing two different strategies to motivate users to continue recording data necessary to receive personal BG forecasts. We used a social approach (i.e., email nudging) as well as an analytical one (i.e., providing a population-wide BG forecast based on an average type 2 diabetic) to boost engagement. I found that, based on usage data, providing a BG forecast as soon as the person started using the app, even if it was not a personalized forecast, encouraged users to log more meals [Hwang '18a]. However, we have yet to find out whether low-fidelity computational insights can maintain user engagement long enough to enable computations with desired levels of personalization. As an alternative solution, I am devising gamification features to increase engagement in users.

Future Research Agenda

Gamified systems are often incorporated into self-monitoring based health interventions as they can help tackle challenges such as the cold start problem by providing the right balance of reward and punishment, and of collaboration and competition to encourage user participation. However, gamification has also been criticized as it sometimes subverts intrinsic motivation by pushing users towards seeking and only responding to extrinsic rewards. This often occurs when **learner agency** is ignored. Therefore, in future studies, I plan to apply socially-based gamification mechanisms in health analytics solutions that are based in self-directed learning theories, where the learner takes an active role through goal setting, problem solving, and reflecting. In this way, I can adopt helpful gamification mechanisms without sacrificing learning opportunities to address low engagement problems in data-driven health management interventions. In addition, I plan on continuing deployment of mHealth apps in-the-wild so that these tools are publicly available, and such research prototypes have an opportunity to engage with users outside of a laboratory setting. The more tools we as academics deploy out in-the-wild, the more real user input we can incorporate to develop better and practical tools for the public.

There is a wide range of interactive tools for self-management and wellness. Much research utilizing such tools emphasizes the behavioral change aspect, however, there is considerably less research investigating **learning and skill development** aspects of the health management problem, particularly in regards to experiential learning outside of the classroom. My plan is to leverage my background in education to focus on these understudied phenomena. One of the crucial reasons why learning is important is because of the structural and political factors that fuel North America's waistline. For example, tax driven re-zoning encourages fast food chains to expand in poor neighborhoods. I have observed the impact of these policies in Washington Heights with my research populations and have first-hand experience seeing how food knowledge is the greatest strength and power for maintaining one's wellbeing. I seek to integrate health and learning to build an environment that empowers underserved populations to take charge of their health and wellness.

With this vision in mind, my goal is to leverage the universally available technologies to help users stay engaged in a form of learning that empowers them to take charge of different aspects of their lives. Especially as an educator, I believe in developing a **life-long learning culture** and addressing the challenges low-income and low-literate populations face from chronic health management and lack of access to resources such as healthcare. I plan on expanding theoretically grounded research to develop new data-driven solutions tackling the current challenges by explicitly addressing learning by leveraging educational theories. These solutions will deliver **health learning content** that is both intrinsically motivating to explore, and easily accessible and comprehensible to all populations at scale.