Smartwatch-Centered Design and Development in Mobile Computing Classes

Andrey Esakia
Department of Computer Science
Virginia Tech
Blacksburg, VA
esakia@cs.vt.edu

Lindah Kotut
Department of Computer Science
Virginia Tech
Blacksburg, VA
lkotut@vt.edu

***Abstract*—In this Research-to-Practice paper, we describe our approach to using smartwatches in a college level computer science class. Smartwatches are unique in the way they provide an interface for interaction–similar to smart phones, while also leveraging affordances inherent in wristwatches such as glanceability. This hybrid nature is especially useful as a means for guiding design scenarios in classroom instruction. We first considered different application domains such as community physical activity and how they leveraged smart watches. From these domains, we elicited general ground rules that inform our approach for using smart watches in a computer science course. We then synthesize and describe five design guidelines that directed our approach to teaching and evaluating students' designs. We assessed and evaluated these guidelines in a third-year level mobile computing class where students were asked to consider them as part of a three-week design and development assignment. After concluding the assignment, the students were asked to complete a survey to capture their experience with the use of the design guidelines, and to also provide general feedback on the suitability of these design goals. Throughout these exercises, we found the design guidelines to be especially useful in three ways: in providing small-screen specific design and development experience, in affording practice and reinforcement of core mobile computing topics, and as a means to meaningfully contribute to socially relevant projects. We contribute to the computing education corpus by detailing the five design guidelines, how they can be used to lead higher-level computer courses, and how they can be used as a lens in considering design approaches in general.**

***Index Terms*—Smartwatch; Mobile; Health and Wellness; Design**

I. Introduction

A Smartwatch can be defined as "an electronic wristwatch that is able to perform many of the functions of a smartphone or tablet computer" [1]. Smartwatches allow users to access a wide range of information at a glance, which has led to an increased user demand–as highlighted by a recent market report that showed that demand exceeded the market capitalization of fitness trackers [2].

From the computer science education perspective, the mainstream smartwatches (WearOS and WatchOS based platforms) are very similar to the smartphone platforms (Android OS and iOS correspondingly). They are derived from their smartphone counterparts in terms of the knowledge, skills and tools required to develop software for, thus making them appealing and easy to adopt from an educator's perspective.

The unique smartwatches form factor, manifested in quickly accessible small displays, offers a new dimension in terms of the potential lessons that students can learn by designing and developing around these capabilities. For example, research in the domain of physical activity promotion has shown that users prefer a brief look at the provided feedback [3]: the glanceable nature of smartwatches, much like the fitness trackers, can be used to accommodate such behaviors [4]. It is notable that smartphones, despite being more ubiquitous than smartwatches, are suitable for providing users with glanceable awareness through microinteractions (low interruption interactions in under 4 seconds) due to the interaction burden associated with the device form-factor [5], [6].

When compared to fitness trackers, smartwatches feature bigger screens, and thus are capable of providing more feedback. This can be very helpful in group based physical activity promotion programs where users need to receive granular, group related feedback, for example: *''You are third in the team"*, in addition to the individual ones – for example: *"Number of steps you've taken today"*.

Smartwatches, while promising and potentially interesting to students as a tool to learn mobile application design and development, present a challenge to the educators that seek to help students in designing meaningful smartwatch applications. The present challenge is the lack of clarity on how to guide students in their application design efforts in a way that will ensure a focus on the unique form factor of smartwatches: the capability of presenting glanceable information using the small display.

To ford this gap, we leverage a combination of intensive related work analysis, a review of current commercial solutions for promoting wellness, and our own work in community health promotion via smartwatches, to present five guidelines for smartwatch-centric design that focuses on leveraging the glanceability of smartwatches. We detail our assessment of the use of the guidelines in a three-week long, WearOS smartwatch-focused module, which was a part of a junior level mobile software development class.

The rest of this paper is organized as follows: we start by presenting a background on mainstream smartwatches and outlining our motivation of this paper. We follow this with an overview of research in related domains. We then describe how the guidelines were derived, and use the remainder of the paper to describe the class module and the assessment of our use of the guidelines.

II. Background and Motivation

Wrist watches have been in use since the late 19th century by soldiers to coordinate time in warfare conditions [7]. Smartwatches use the same form-factor, but offer fully programmable watchfaces that convey information as non-interruptive updates [4]. Recent studies have shown that smartwatch users glance at the watchface several times per hour to mostly check time [4], [8]. During such glances, users are likely to notice other feedback on the watchface [4]. This reveals the opportunity to be able to envision smartwatch designs that are able to frequently catch and satisfy a user's attention without the detrimental cost of interruption.

Users are more likely to be annoyed by interruptions and would seek to get rid of the sources of interruption, unless these interruptions are considered critical [9]. Thus smartwatches offer a unique ability to frequently provide a means to catch users attention, without causing interruptions. These means of providing updates is particularly valuable for programs designed to inspire behavior change by providing continuous feedback as a means of influence. The latest evolution of the mainstream smartwatch platforms recognize this capability, and accordingly tailor the user experience towards supporting brief glances.

From the computer science education perspective, it is important to recognize the utility offered by smartwatches, and prepare future designers and developers accordingly. In this paper, we argue that the use of smartwatches in the domain of computer science education can be beneficial in three ways: (1) the smartwatch constraint in the form of small and (typically) round screens can help train students in user interface design and implementation of 2D graphics. (2) The smartwatch's similarity with smartphone development can be helpful in both practicing and reinforcing the core mobile computing topics. Finally, (3) the glanceable nature of smartwatches can be helpful in pursuing socially relevant initiatives where user awareness of information plays a key role.

III. Related Work

While smartwatches have been explored in the education setting as tools for providing contextual information on the wrist [10], the literature on smartwatches from the perspective of computer science education is yet scarce. In our previous work [11], we explored Pebble smartwatches in the context of an upper level mobile software development class, and concluded that the hardware limitations of Pebble: such as the need to program in the C language, as well as the ability to exchange data with the companion smartphone, offer a novel way to reinforce core computer science topics. We also recognized that the small screen and the unique form-factor of the smartwatch presented new possibilities in terms of design-centric assignments, because such form-factors are associated with quick information access. We subsequently argued that the smartphone education should be one of the core mobile computing class modules [12].

In terms of the benefits of small-screen focused design and development, it has been shown in the context of a mobile computing class, that designing for varying screen sizes present a valuable challenge for students requiring additional considerations–an important skill that is helpful for developing Human-Computer Interaction competencies [13]. For platforms like Pebble, the challenge of dealing with the small screen size is compounded by the need to deal with the monochrome screen which also requires additional processing to display visualizations [11]. However, the Pebble has been discontinued,[1] and current smartwatches feature full color displays which do not require such processing.

Designing socially relevant projects in the computer science education context that engage students in projects with real-world applications have been shown to provide benefits beyond a straightforward community support. Pauca et al. [14] argue that such efforts can spawn real world projects attracting multi-disciplinary stakeholders that ultimately collaborate towards large-scale versions of the initial projects. Van et al. [15] further claim that by working on socially relevant projects, students have the opportunity to demonstrate and apply competencies and externalize their own experiences and values. Murphy et al. [16] approach this from the development of a specific skill-set development, and argue that through working on real-world problems, students can develop a sense of self-efficacy with regards to collaborations and adherence to specific software engineering methodologies.

IV. Five Design Guidelines

In this section, we present five design guidelines that are aimed at helping current or future designers and developers to focus on the ergonomic advantages of smartwatch devices. We support each guideline by scientific evidence. We focus on interventions where small groups of socially connected individuals track progress, compete and cooperate with each each other, with the ultimate goal of increasing physical activity levels. While the guidelines underlying themes are based on these domains, they are expandable beyond this specific domain.

1) *Delegate prominent watchface space for typical (smart)watch functions*. Prominently displaying time and other desirable indicators that are found on most (smart)watches ensures that users can see expected, familiar, and utilitarian indicators on the watchface at all times. The justification for this requirement is supported by research suggesting that users glance at the watchface multiple times per hour [4], [8] and that the primary reason for glancing is to check time [4].
2) *Provide frequently updated glanceable summaries*. Displaying summaries of information such as physical activity progress levels, comparative progress levels (between

[1] https://www.theguardian.com/technology/2016/dec/08/kickstarter-pebble-shut-down

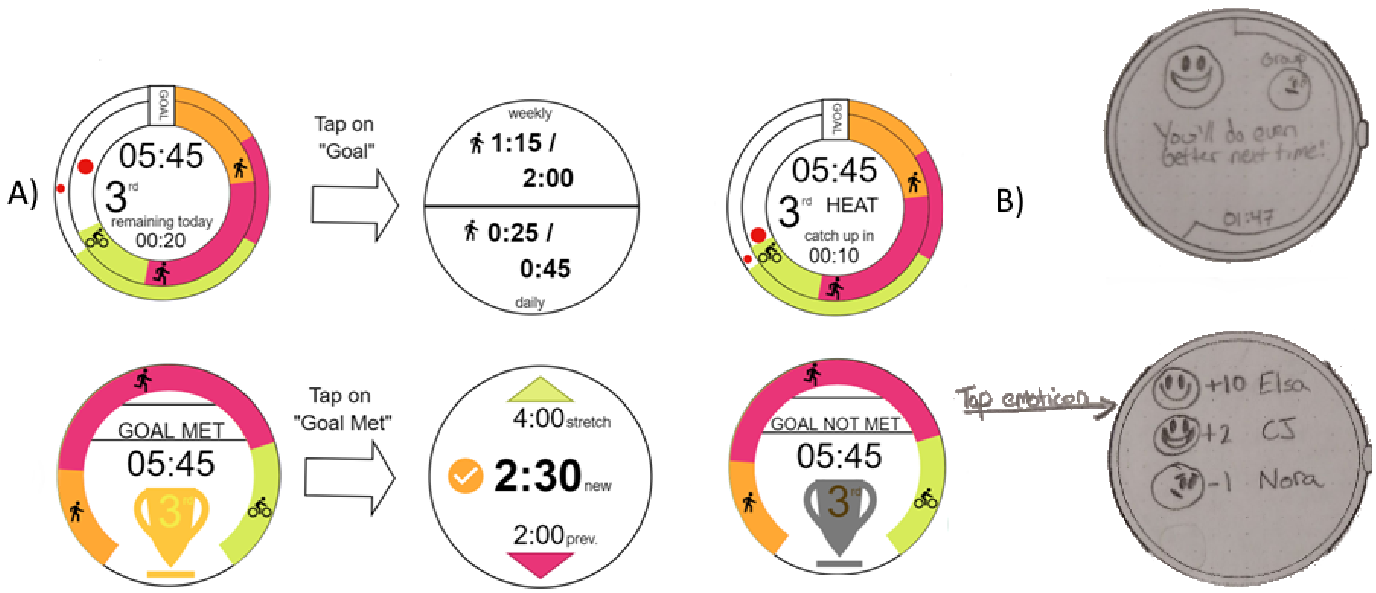

Fig. 1. A: a design that seeks to convey group and individual physical activity progress via concentric arcs. The nearest competition is visualized with red dots. Tapping on the watchface elements reveals dialogs with details. B: a design that combines arc with emoji. The emojis are used to convey an emotional summary of the individual and group progress. Tapping on an emoji reveals a dialog with more detailed information.

individuals, groups etc.) is a way to leverage the fact that users frequently look at the watchfaces and have their eyes ready to capture peripheral glanceable information. This design strategy is based on the observation that mobile device users react negatively to interruptions from non-critical notifications [9], both in general use and in wellness tracking contexts [17]. A typical user interaction with wellness feedback is via brief glances (under 4 seconds) [3]. This has been shown to be true in smartwatches as well, [18] and frequently updated feedback leads to user interest in the presented information [19], [20] and ultimately encourages checking habits [20], [21], [22].

3) *Present users with information about quickly attainable goals*. Because users frequently check the watchface, presenting them with quickly attainable goals might increase a chance of influencing their individual or group decisions. This design consideration is derived from the observation that smartwatch users pay attention and react to attainable goals presented on the watchface [20].
4) *Allow users to quickly obtain extra details of the summaries*. Interactive watchfaces and notifications have the capacity to offer extra information via quick (less than 4 seconds) interactions. This might incentivize users to seek and have access to feedback due to the fast access time. This design guideline is based on the fact that current smartwatches provide interactive watchfaces where users can access extra information via simple tap or swipe gestures. Other research on mobile device usability suggests that users are more likely to engage with a device if the anticipated action can be accomplished as a micro-interaction (less than 4 seconds in duration) [6]. It is also motivated by the findings by Gouveia et al. [20] which recommend glanceable feedback for eliciting further user engagement with the presented information.
5) *Delegate non-glanceable details onto the smartphone*. Smartwatches' small screens, while useful for glanceable interactions, are not ideal for longer operations (over 4 seconds). Smartphones are ideal for operations requiring longer interactions that involve complex information, for example a operating multi-column spreadsheet – which would be cumbersome if operated from a smartwatch. For these complex interactions, users would rather use the smartphone that has much larger screen space for touch points and for presenting non-glanceable information. This design guidelines builds on guideline #4 as it recognizes that not all feedback can be accessed via micro-interactions and on a small display. Feedback of this kind should be delegated to the companion smartphone application.

V. CLASS

The guidelines were motivated both by the increasingly more mainstream status of smartwatches, and the potential educational benefits rooted in their uniqueness. These guidelines were exercised as part of a design-focused and socially relevant multi-part assignment in a junior-level mobile software development class at Virginia Tech.

A. Class Overview

The entire course consisted of multiple modules spanning topics on user interface, connectivity, sensors, among others. Each module sought to teach core topics of mobile computing in the context of Android OS and spanned a period between 10 and 14 days depending on the material intensity: *GUI* (Creating basic apps with interactive user interfaces), *Activity and Fragment* (use of multiple Fragments within an Activity, handling life-cycle events with multiple Fragments), *AsyncTask and InstanceState* (basics of short asynchronous operations and app persistence across life-cycle events), *Data and Internet* (data persistence and communication via HTTPUrlConnection), *Service and BroadcastReceiver* (use of background services and OS-wide communication/messaging), *Location and Sensors* (use of GPS and other sensors in foreground and background), Touch and Graphics (use of CanvasAPI to create custom 2D graphics and View elements) and finally, a module dedicated to smartwatches. Following the recommendations of Seyam et al. [23], each module consisted of a lecture, a tutorial, pair-programming activity, and a homework assignment.

B. Smartwatch module

The smartwatch module sought to teach students the core skills necessary to build smartwatch-based systems that leverage the smartphone glanceable feature. In this module, the students learned to design and build custom watchfaces (mostly focused on use of CanvasAPI in the watchface context), to capture and preserve physical activity data using the integrated sensors (Via GoogleFit API) and to communicate data between the smartwatch and the companion smartphone (Via DataAPI and MessageAPI which are necessary to exchange data with the paired smartphone). It should be noted that this module was strategically taught as the final module because WearOS development has many overlaps with the "normal" Android OS hence the assumption that the students could "re-use" the skills acquired during the smartphone-focused modules (For example, watchface-based pop-up dialogs were created using XML layout files just like the UI layouts on Android OS).

The objective of the homework was to design a smartwatch-centered system that would tackle the nationwide epidemic of physical inactivity by channeling individual and group based behavioral strategies. As part of the homework description, students were given necessary resources to familiarize with a set of behavioral strategies. Students were also given a range of available information that they could capture and convey as part of the behavioral strategies (based on the capabilities of GoogleFit API).

In **Part I** of the assignment, the students were required to produce high fidelity wireframes applied to a set of scenarios necessary to showcase the design concepts. Specifically, the students were required to show in their designs and scenarios, how the proposed ideas would help the intervention in conveying the behavioral strategies to promote the hypothetical users' physical activity. To aid students with the design, the homework description included materials necessary to provide basic understanding of the behavioral aspects of the interventions' principles (e.g., description of how individual strategies such as goal setting, self-monitoring and interpersonal strategies like competition and cooperation typically work). Furthermore, the assignment provided a list of types of physical activity data (based on the capabilities of Google Fit API) that can be captured and used to facilitate the behavioral strategies (e.g., number of steps, physical activity duration in minutes, goals, activity types etc.). Finally, to help students with the scenario selection, they were given numerous templates from which they were required to pick at least three following the prompt: *"Create at least three scenarios that will convey the strategies of competition, goal setting and cooperation"*. The assignment was graded based on the quality of wireframes, scenarios, and evidence of applying the behavioral strategies.

As part of the second assignment (**Part II**) the students were given the five guidelines and were asked to revise their designs (the guidelines were accompanied with a supplementary material that provided brief explanations of each of the guideline). Students were also asked to document their use (as well as non-use) of the design recommendations via a web survey. We deliberately introduced the guidelines only after the students had spent some time on the assignment. We rationalized this approach because we believe that after spending substantial time and energy on the design in Part I, the students would be better prepared to comprehend the guidelines and report on their decision with regards to use or non-use.

The final part of the assignment (**Part III**), was made effectively optional (the lowest grade of the three parts was dropped), and it required students to implement the proposed design into a working system integrated in the the back-end of the statewide intervention. The statewide intervention featured a live website with an API that students could use to send and receive data. This assignment required students to implement a smartwatch-centered system that at a minimum, would accomplish the following: track physical activity data, persists data, frequently communicate data to and from the back-end, provide visual feedback updates on the watchface with interactivity (e.g., *"Tap to open a dialog with more details"*).

VI. Assessment

Our motivation stemmed from the need to assess the use of guidelines in the context of a socially relevant assignment. Specifically, we were interested in investigating how the undergraduate students interpret and apply (if at all) the five guidelines to design smartwatch systems that promote physical activity behaviors, and whether this experience reinforces smartwatch specific design, core mobile topics, and yields the common benefits of working on socially relevant projects. Survey responses were summarized and student comments analyzed.

A. Method

The degree of adherence to the design recommendation was measured using a set of basic rubrics established by three HCI experts involved in the statewide intervention, who also had experience teaching the course. Each element of the rubric represented a minimal understanding of the recommendation, reflecting whether a student understood its meaning and applied it in at least a minimal way. The experts agreed that each element of the rubric was both relevant and unambiguous. The adherence to Guideline #1 for example, as judged by its efficacy in answering the question: *"Did the student include time indicator on the watchface?"*.

In terms of the experience with the guidelines, the students were required to complete a Qualtrics survey where they indicated whether they had followed a given guideline in the original design, and whether they chose to follow it or not. For either of the answer types, the students were also required to elaborate via free form text by answering the prompt: *"Explain why you chose not to follow [the Guideline]?"*.

The code from the optional third part of the assignment was analyzed in terms of the features implemented, and APIs used.

B. Results

Thirty four students completed all the assignment parts in addition to the survey. In over 70% of the responses, students stated that they were already following the guidelines in their original design, with 23% of the responses claiming to have revised their initial designs(s) to follow at least one of the guidelines. Three students actively chose not to follow guideline #3 (*Present users with information about quickly attainable goals*) in the revision part of the assignment.

The students who chose not follow the guideline did so because they perceived a design conflict with their initial approach and how it would implicate the user:

> "*I decided not to follow this guideline, because I designed my app such that the app displays either a daily goal or a long-term goal. Since the goal changes on a daily basis, breaking the goal into smaller goals may cause confusion to the user.*"

Or if they conflicted with their originally stated goals:

> "*I felt it didn't fit very well with my original goal design. Goals in my application are created by the user, and the user can customize the goal, but does not receive recommendations.*"

Of the 34 students who completed the assignments and the accompanying assessment, 26 of them included a time indicator for their watchface design that had a height of no less then 10% of the total screen height thus confirming to the first guideline. Four students included time indicators smaller than 10%, and three did not include it at all. From the survey responses, we found that the students who did not follow this guideline seemed to have either misrepresented it:

> *"I implemented this on the smartwatch by showing familiar and consistent screens."*

Or misunderstood it:

> *"I'm not sure what this recommendation really means. Does it mean that I have to implement a watch face that show my app information on the smart-watch all the time?"*

Designs from 14 students included more than one glanceable indicator for both individual and interpersonal feedback (Guideline #2). The rest of the students either included only personal feedback indicator, while delegating the interpersonal feedback to active notifications, or used non-glanceable feedback in its place. Eleven students included glanceable indicators for quickly attainable goals (Guideline #3) and the remaining 21 students either used non-glanceable, disruptive means of presenting attainable goals, or presented vague message summaries. 24 students produced designs that allowed access to additional details with a simple tap or a gesture (Guideline #4).

Three students did not provide include the functionality described in Guideline #4 despite claiming to have done so in the survey. Another three students included extra detail dialogs, but in the form of notifications pop-ups that are not controlled by user inputs. The remaining four students provided access to additional details but either with multiple interactions or presented information that is not related to the watchface glanceable indicators. Finally, all but one student followed the delegation guideline (Guideline #5). The one student duplicated all of the smartwatch interactions and design into a smartphone format.

System implementation was an optional part of the assignment in which nine students chose to complete. Of these: six completed all the assignment requirements, and earned full points. A full implementation required students to leverage Google Fit API to capture steps via the smartwatch and persist the data on the smartphone's SQLite database (persistence). The students had to periodically upload this data to the statewide interventions server and retrieve rankings (connectivity via HTTPUrlConnection) which in turn would be periodically transferred to the watchface (Bluetooth data exchange via DataApi), and displayed via glanceable and interactive visualizations (CanvasAPI and event driven programming).

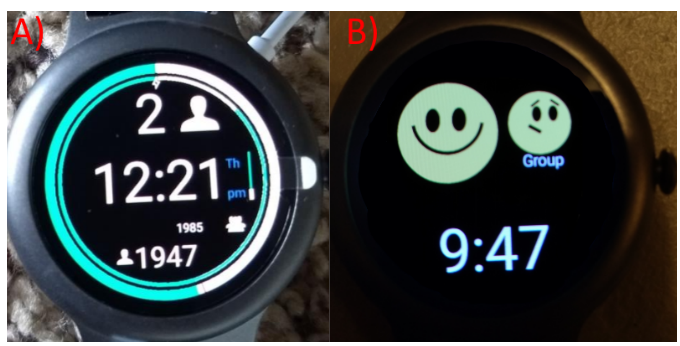

Fig. 2. Students implementation of the design from Figure 1A and 1B. These watchfaces follow very different approaches: 2A uses straightforward visualizations such as numbers, text and simple shapes to convey feedback, 2B, on the other hand, uses emoji to aggregate the individual and group progress values into an emotion. This design requires users to tap on the emoji in order to see more specific details about the progress (See Figure 1B).

Five of the six students used progress lines and arcs to indicate progress via glanceable feedback on a small screen: such visualizations required students to interpret progress data retrieved from the web (e.g., collective group goal and current progress) and dynamically draw an arc on the Wear OS watchface (See Figure 2). This task required mathematical translation of the progress information (i.e., each 1% of the daily goal translated to 3.6 degrees of the arcs circumference). The students further made the progress indicators interactive by assigning callback methods that invoked dialogs with additional details (the dialogs were implemented using traditional XML based Android layouts). One student used emojis as means of visualizing individual and group progress (See Figure 2B).

Two designs (See Figure 1) adhering to all design guidelines were selected as a proof-of-concept to be used in the statewide physical activity interventions for future smartwatch-based solutions. The first design (Figure 1A) was recognized for its balanced representation of numerous behavioral strategies via simple and glanceable visualizations, while the second design was recognized for its impactful and engaging means of communicating the feedback (Figure 1B).

VII. Discussion and Conclusion

The expert assessment of the designs as well as the survey responses show that the guidelines were generally well received and understood by the students. We found that the third guideline (*"Present users with information about quickly attainable goals"*) was not adhered to as consistently as the other four guidelines and, as suggested by the survey responses, it is likely because the students misunderstood the behavioral rationale behind the guideline. In future work, we would improve this by being more thorough in communicating not only how to interpret the guidelines, but also in highlighting the scientific background backing the guidelines, as a means of providing a rich resource that would help the students in making decisions regarding guidelines use/non-use.

The design guidelines encouraged students to leverage the inherent 'glanceability' of the smartwatch watchfaces, and its application in the context of a socially relevant project aimed at promoting community physical activity. Students made decisions about how to package and represent various forms of feedback on the watchface in a glanceable fashion. Students that built the apps, used arcs to visualize physical activity progress. The use of arcs required them to perform mathematical computations in order to translate units of progress into visible increments. Overall, by designing for small, glanceable and round screens (that are common in mainstream WearOS smartwatches), the students gained valuable and, arguably, unique perspectives in design especially in the Human-Computer Interaction domain.

Beyond the user interface design, the results of the student code analysis revealed that multiple-core mobile computing topics were exercised as part of the effort to create working systems. The student-made apps captured physical activity data (sensors), sent and received physical activity related data (device-to-device communication and event driven programming), and updated visual feedback (managing 2D graphics). Further, students implemented watchface interactions where screen taps triggered revealed pop-up dialogs with extra details about the selected indicator (this required creating XML layouts and implementing callback methods similar to Android OS development).

Perhaps the most encouraging outcome was related to the work by two students (See Figures 1,2) that were distinguished by the HCI experts during the assessment phase. The experts evaluators were also part of the statewide physical activity intervention project. The two students were invited to join the research team working on the design and development of the actual smartwatch-centered system to help with the statewide physical activity promotion efforts. It is also important to note that the two designs took very different approaches to conveying individual and group feedback, as one of the designs employed direct means of conveying feedback via numbers and simple shapes, while the other design employed emojis and text as a way convey emotions associated with the given progress at a given time. This observation illustrates one of the main benefits of socially relevant projects in the classroom setting: it allows students to manifest their unique perspectives. These observations suggest that the five design guidelines proposed in this paper retain sufficient room for creative expression.

We make two-fold recommendations to the instructors who are interested in pursuing smartwatch design in the classroom. First, we recommend adopting smartwatches into mobile computing teaching practice because: (a) smartwatches are becoming mainstream and hence it is wise to accommodate the inevitable demand from the students; (b) developing for mainstream smartwatches is very similar to developing for smartphones – making it easier to integrate into an existing mobile computing class; (c) the core topics in mobile computing are also applied to smartwatch development – which allows for more specialized pedagogy (eliminating redundancies); and (d) smartwatches can be used as a novel platform for familiar and socially relevant projects. When coupled with the novelty of the form factor, this can lead to new perspectives. Second, we recommend keeping the glanceability and information accessibility as the main theme for teaching smartwatch-specific content and using the five guidelines presented in this paper as a starting point.

We seek to apply the five guidelines to other socially-relevant projects beyond the physical activity promotion domain. We wish to further evolve the guidelines by exploring other domains where the inherent ergonomic advantages of smartwatches can be as useful.

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