Germ Destroyer – A Gamified System to Increase the Hand Washing Duration in Shared Bathrooms

Maximilian Altmeyer, Pascal Lessel,
Marc Schubhan, Vladislav Hnatovskiy, Antonio Krüger
German Research Center for Artificial Intelligence (DFKI)
Saarland Informatics Campus, Germany
firstName.lastName@dfki.de

ABSTRACT
Washing hands is important for public health as it prevents spreading germs to other people. One of the most important factors in cleaning hands is the hand washing duration. However, people mostly do not wash their hands for a long enough time leading to infections and diseases for themselves and others. To counter this, we present "Germ Destroyer", a system consisting of a sensing device which can be mounted on the water tap and a mobile application providing gameful feedback to encourage users to meet the recommended duration. In the mobile application, users kill germs and collect points by washing their hands. Through a laboratory study (N=14) and a 10-day in-the-wild study (363 hand washing sessions), we found that Germ Destroyer enhances the enjoyment of hand washing, reduces the *perceived* hand washing duration, almost doubles the *actual* hand washing duration, and has the potential to reduce the risk of infection.

CCS Concepts
•Human-centered computing → Empirical studies in HCI;

Author Keywords
Handwashing; Gamification; Health; Persuasive Technology

INTRODUCTION
Washing hands is one of the most important – and at the same time simplest – ways to prevent getting sick and spreading viruses or bacteria to other people [18, 24]. Research has shown that improvements in hand hygiene are directly associated with lower rates of infectious illnesses [1, 10]. Therefore, hand washing is an essential method to prevent infections and diseases such as food poisoning, flu or diarrhea [1, 12] and is especially important in shared bathrooms [10]. However, hand washing after using shared bathrooms is heavily neglected [19] and often performed for a very short time [18]. This is problematic, as the time taken to wash one's hands has been shown to be a key factor for removing microorganisms [28]. Research suggests that washing hands for 15-20 seconds is most effective [18] and many countries and organizations such as the Centers for Disease Control and Prevention followed this recommendation [8]. However, it was found that less than 6% of people follow this recommended duration [5]. Furthermore, a study by Wirthlin Worldwide and Bayer Pharmaceutical [31] found that 32% of subjects did not wash their hands at all after using public restrooms. This is supported by a study by Guinan et al. [14] revealing that 42% of the female and 52% of the male subjects did not wash their hands when using a public restroom. Therefore, encouraging people to wash their hands and meet the recommended duration is important and has great potential to enhance personal and public health.

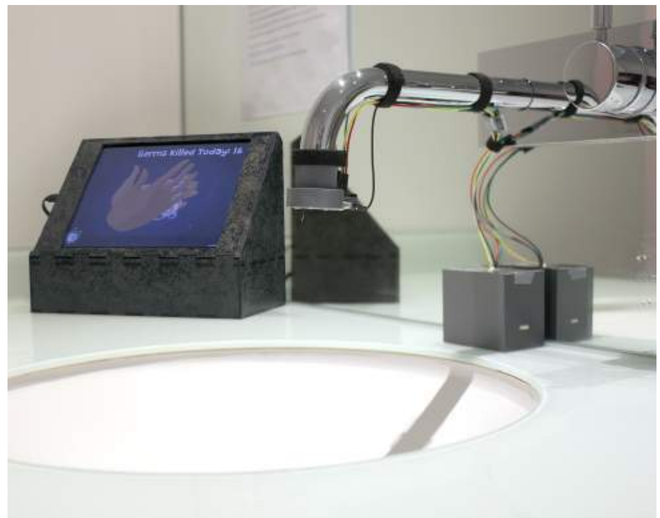

Figure 1. Our system during the in-the-wild study: A 3D-printed measuring unit which can be mounted on the tap and a gameful mobile application. The measuring unit detects whether water is running and whether hands are present or not and sends this information to the mobile application.

Given this potential, we present "Germ Destroyer", a gameful system consisting of a wireless measurement unit which can be mounted on the water tap and a mobile

CHI PLAY '19, October 22–25, 2019, Barcelona, Spain

ISBN 978-1-4503-6688-5/19/10 ...$15.00.
https://doi.org/10.1145/3311350.3347157

application providing real-time feedback to the user. The goal of this system is engaging users and motivating them to wash their hands for the recommended duration of 20 seconds in order to enhance hand hygiene and thus prevent infectious illnesses from spreading in shared bathrooms. To reach this goal, we make use of gamification, i.e. the use of game elements in non-game contexts [11], since it has been successfully employed in health-related domains before [27].

In this paper, we contribute the hardware and software design of a wireless device to measure the hand washing duration as well as a gamified application motivating users to wash their hands for a long enough time. The application shows animated germs representing the contamination of hands. By washing hands, these germs steadily disappear and the user receives points. Moreover, we contribute results from a user experience evaluation in the lab and from a ten-day in-the-wild study showing that our system provides an enjoyable user experience, has positive effects on the *perceived* washing duration, successfully motivates users to increase their *actual* hand washing duration and has the potential to reduce the risk of infection in shared bathrooms.

RELATED WORK

We situate our work in the field of gamified systems encouraging a healthier life. Thus, we start this section by presenting relevant research in this domain. Next, we present research about hand washing practices and investigations putting a focus on how to motivate people to wash their hands properly. Last, we outline hand washing interventions in the field of Human-Computer Interaction.

Gamified Systems Encouraging Healthy Lifestyles

Criteria for a healthy life are very multifaceted, and adhering to healthy lifestyle habits is not easy for most people [20]. Therefore, gameful interventions aiming at encouraging people to live healthfully in various domains have been developed and investigated. For instance, Lessel et al. [22] developed a device called "WaterCoaster" to measure the drinking amount of people by using a scale and transferring data wirelessly to a mobile application. The mobile application visualizes a virtual marine animal whose emotional state is connected to the drinking behavior of users. By drinking a healthy amount of liquid, users receive upgrades for their virtual character such as glasses or hats. In a user study, the authors found that the system subjectively leads to positive behavioral outcomes and that the virtual characters used in the system were perceived particularly well. This motivates our approach of using virtual characters to provide feedback playfully.

Schaefbauer et al. [26] investigate the effectiveness of a mobile application called "Snack Buddy", which aims to promote healthy snacking behavior among low socioeconomic status families. The app allows families to both track their snacking and receive feedback on the healthiness of their snacks. Also, the system allows a review of the healthiness of snacks of other family members and a gameful interface is available for children and teenagers in the families, showing an avatar progressing through life goals. Progress can be made by getting snack healthiness points. The study revealed that the system successfully led to a decrease in the number of snacks, and that participants appreciated the social and gameful features of the system, motivating our approach of integrating gameful normative feedback. In the physical activity domain, Altmeyer et al. [2] developed a system to encourage users to increase their step counts using a gamified mobile app and a gamified public display showing the step counts of all users. In a three-week in-the-wild study they found that the gamified public display increased users' step count significantly and positively affected their intrinsic motivation, caused by a higher feeling of social relatedness. Since we also provide gameful feedback publicly, we expect similar positive effects.

Hand Washing Practices and Behavior Change

The importance of hand washing for personal and public health has been validated by numerous investigations in the past, dating back to the work by Semmelweiss in the 1800s [21]. Also, hand washing is considered as the most cost-effective way to improve public health [10]. However, washing hands after using the restroom is often not done well or at all [19]. Consequently, research has been carried out about hand washing practices and how to change people's attitude or behavior toward washing hands properly. Consistently, studies report differences in hand washing practices between male and female subjects [5]. Johnson et al. [19] conducted observational studies in public restrooms and found that 61% of the women and only 37% of male subjects washed their hands after restroom use. Similar results are reported by Kinnison et al. [21]. They found that less than one third of participants washed their hands properly (such that it would effectively reduce contamination) and that females were more likely to wash their hands properly than males (44.8% vs. 17.9%). This gender difference was also reported by Guinan et al. [14], showing that 58% of female subjects washed their hands after bathroom usage and only 48% of male subjects.

Edwards et al. [24] investigated predictors of hand washing behavior and found that having an observer present in the restroom influences hand washing behavior positively. Of those participants who had no observer present, 70% washed their hands, while 90% of those who had an observer present washed. Besides that, the authors replicate the aforementioned gender difference. The positive effect of having others present while in the restroom was also found by Nalbone et al. [25]. Here, the authors found that 90% of the subjects washed their hands while other people were present whereas only 44% did so when alone in the restroom. We expect that the presence of our system might lead to similar effects. Borchgrevinket al. [5] report findings from a study of hand washing practices conducted in a college town environment, where the effect of using signs encouraging hand washing was investigated. They found that when signs were present in a restroom, the average washing time (which is considered a key factor for proper hand washing) climbed from 6.50 to 7.08 seconds on average. Besides showing that providing feedback (similar to our approach) positively influences hand washing, this study also shows that the average washing duration (6.50 seconds) is far below the recommended duration of 15-20 seconds [18].

Furthermore, Curtis et al. [10] note in their literature review that key motivations for hand washing are sticking to social norms and promoting disgust. As such, positive effects of studies conducted in a public restroom and in a train station, that used people's disgust as feedback in a humorous way, are reported. Also, the use of normative feedback in the form of a text message saying "Is the person next to you washing with soap?" is outlined as being very successful in encouraging hand washing behavior in a motorway service station. Also, Smith et al. [28] investigate determinants of hand hygiene and which factors are most important. They found that a 20-second hand wash is more effective for removing bacteria than using a gel sanitizer with 70% alcohol. They also note that washing one's hands for less than 5 seconds is potentially even worse than not washing them at all. Additionally, the authors highlight that hand disinfection damages the skin flora, leading to skin irritations. Similarly, hand disinfection is considered to encourage bacteria developing antibiotic resistances [1], which is why usual hand washing should be performed in everyday life. Considering good hand washing practice, the duration of hand washing and the degree of friction during lathering were found to be most important [28].

Hand Washing in HCI

The importance of hand washing is also reflected by numerous interventions in the HCI domain. For instance, Arroyo et al. [4] present "Waterbot", a system that can be attached to the water tap, and aims to ensure safety at the sink. The authors propose design ideas for several use cases. Among others, "CleanSink" is presented. This system uses a CCD camera to detect the presence of hands under the water stream and a flashing light indicates when sufficient time has passed. In contrast to our system, the device is stand-alone, not connected to a game or using any gameful features, and remains a conceptual idea, i.e. it was not implemented nor tested in a user study. Moreover, the use of optical sensors (CCD cameras) in the bathroom is threatening to the privacy of users [23] and is considered as a criminal offense in most countries. Asai et al. [3] present a system to raise awareness of proper hand hygiene. In the user interface, they show a message reminding people passing by to disinfect their hands. Once a user pushes the pump type antiseptic container, a message is shown stating "Thank you for your cooperation". The system was tested in the entrance area of a hospital, a school and a cafeteria, showing positive effects on the users' behavior. However, the system did not focus on hand washing or using gamification but on hand disinfection and feedback. Given the aforementioned work by Smith et al. [28] showing various drawbacks of hand disinfection in daily life, washing the hands instead of disinfecting them seems more conducive to a healthy lifestyle.

Similar to the aforementioned work, Mondol et al. [23] aimed at building a system reminding food workers to wash their hands more frequently using wrist-worn smart watches. However, the focus of their research was on developing a smart-watch-based classifier able to distinguish hand washing gestures from others. Besides recognizing hand washing gestures, the system reminds food workers to wash their hands frequently and thus ensures proper hand washing compliance. In a technical evaluation, the authors were able to show a high accuracy and robustness of their system. However, as we aim to develop a gameful system for everyday use in shared bathrooms, wrist-worn devices, or any tracking devices that need to be worn by the user, are not suitable. Training surgery staff in proper hand washing virtually was the goal from Corato et al. [9]. They developed a virtual training application to teach surgery staff to follow established hand washing procedures before accessing the operating theater using augmented reality. As requirements, the authors emphasize that such a system should be ubiquitous and unattended. To track hand gestures, they use a web cam and color-based segmentation. A monitor shows the scene recorded by the web cam which is overlaid with a transparent layer showing a video on how to wash hands properly. Besides having the same privacy-related issues as mentioned before due to using a web cam, the system was again not evaluated in the wild.

Summary

Related work has shown that hand washing is still a very relevant topic for public and personal health. However, it has also been demonstrated clearly that in reality, compliance with recommended practices for hand washing is poor. First and foremost, the hand washing duration has been identified as a crucial factor that needs to be improved and encouraged, as people mostly wash their hands very briefly. This has been considered to be even worse than not washing one's hands at all, regarding the amount of germs spread. It was also shown that having an observer or signs present positively affects hand washing behavior. Additionally, social norms and feedback promoting disgust may have a positive impact on users in this regard. In the HCI domain, systems were created reminding users to disinfect or wash their hands.

However, research presented in this section mostly focused on technical aspects like hand recognition instead of using elements known from games to affect users' behavior. Given that past research has demonstrated that gameful systems engage people and motivate them to lead healthier lifestyles, we expect that gamification is a suitable tool to help people wash their hands for a long enough time as well. Also, most of these systems could not be used legally in shared bathrooms due to using camera-based approaches for hand detection. Furthermore, none of these systems has been investigated in the wild. Therefore, the question whether a gameful approach may change people's hand washing behavior, and thus may have an impact on public and personal health, remains open.

In this paper, we close this gap by contributing an open source, unattended system which is installed and evaluated in a shared bathroom. Encouraged by the success of gameful, persuasive systems in other domains, we hypothesize that our system affects people's behavior positively as well.

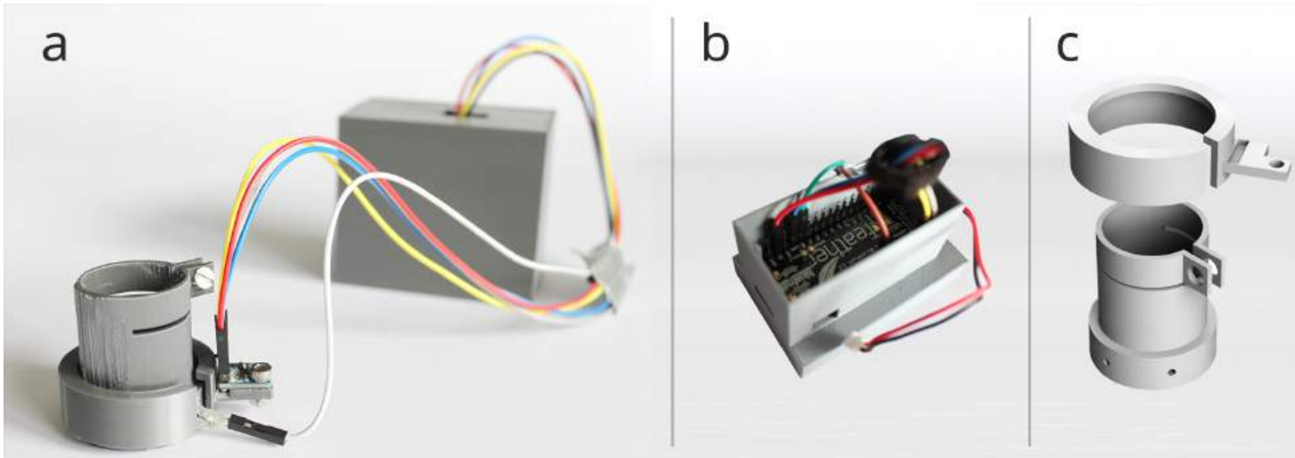

Figure 2. Overview of the measuring device. a) The 3D-printed measuring unit which can be mounted on the water tap. b) The microcontroller in its case. c) The exploded view of the 3D-model.

Based on the lessons learned, we deduce the following design implications for our system:

D1: Focus on hand washing rather than hand disinfection [28]

D2: Encourage a washing duration of 20 seconds [8, 18]

D3: Avoid camera-based approaches and any sensors that can record sound or pictures [23]

D4: Ensure that the system integrates well with its surrounding and is self-attended [9]

D5: Use normative feedback for behavior change [10, 24]

D6: Promote disgust playfully to change behavior [10]

D7: Engage users by using gameful elements [2, 22, 26]

D8: Provide feedback about the washing duration [10, 26]

SYSTEM DESIGN

In this section, we describe the concept and implementation of our system. It consists of two parts – the sensor device and the gamified application – communicating via Bluetooth Low Energy ("BLE"). The sensor device can be mounted on the water tap such that water flows through it. The sensing device also has a base station which is responsible for sending hand washing states via BLE to the mobile application, running on an Android tablet device.

BLE Sensor Device

Since we focus on encouraging a sufficient hand washing duration (**D1**, **D2**), we conceptualized a sensing device which can be easily placed on the water tap, without interfering with the users' intended actions (**D4**, see Figure 2a). In addition, we have a base station which has a wired connection to the sensing device on the water tap. The base station holds the microcontroller as well as the battery (see Figure 2b). We designed the sensing device such that it fits on most water taps (see Figure 1) and can be further adjusted by tightening or loosening a screw located at its edge. All housing parts of our system are 3D printed. Figure 2c shows the 3D-model of the sensing device which is mounted on the tap.

To measure whether water is flowing or not, we used a capacitive sensing approach in the inside of the sensing device's tube (capacity changes as water flows through the tube, determined by a tensioned wire connected to a 1 MOhm resistor). On the outer side of the sensing device, we installed a VL6180X time-of-flight distance ranging sensor to detect whether hands are present or not. The sensor uses a tiny laser source and is able to measure distances between 5mm and 100mm, which perfectly fits our needs. Since only these two sensors are needed, we are able to ensure a completely anonymous tracking process (**D3**), as no personal information can be detected. In addition to building the hardware, we also implemented a firmware to handle, interpret and transmit the measured sensor values to the gamified application (or any other BLE-enabled device). Our device transmits four different states using BLE characteristic notifications:

Idle: No water is flowing and no hands are present

Water Flow: Water is flowing and no hands are present

Hand Washing: Water is flowing and hands are present

Hands Only: No water is flowing and hands are present

Besides sending these notifications, the firmware also allows receiving commands in order to adjust the sensor thresholds (e.g. the threshold which is used to decide whether hands are present or not can be easily set by sending a corresponding message to the device). This firmware is installed on the Adafruit Feather M0 Bluefruit LE module[1]. To ensure a maintenance-free runtime (**D4**), our device also has a 2000 mAh battery, allowing it to run for 200+ hours. It can be easily recharged via a micro USB outlet. Besides sending the aforementioned states, the firmware can also be configured to send the raw sensor readings. To allow fellow researchers to

[1] https://www.adafruit.com/product/2995, last accessed July 17, 2019

Figure 3. Different screens of the gameful mobile application. a) The screen visualizing germs is shown whenever water is running. b) If users remove their hands, germs are shown as getting angry to encourage the user to keep on washing. c) During hand washing, germs are destroyed and generate points. d) After destroying all germs, the app shows an animation illustrating clean hands and all destroyed germs are added to the daily amount of killed germs.

use our system, we published the firmware, API documentation, circuit scheme, a list of electronic components and the 3D models on GitHub[2]. With a price of less than $50, the measurement device can be seen as a low-cost solution.

Gamified Mobile Application

We conceptualized and implemented a gamified mobile application called "Germ Destroyer". Depending on the state transmitted by the sensor device, the app shows different screens and provides different feedback to the user. When water is flowing, the app visualizes nasty germs (see Figure 3a) to illustrate and represent the microbiological contamination. We used germs as virtual characters to promote disgust playfully since it was shown to lead to positive effects on hand washing behavior in public restrooms, encouraging people to reflect on proper hand washing (**D6**). Also, using virtual germs may highlight the impact of washing hands on their real-world contamination, which may enhance the persuasive power of our system [13]. Once users start washing their hands, i.e. put their hands under the tap while water is flowing, soap bubbles and washing animations appear in the app. Also, a progress bar next to a clock icon is shown, providing feedback on how long hands should be washed (**D8**). The progress bar fills at a constant rate until 20 seconds have been reached by the user. With increasing progress, the germs start to move and shake faster as well as change their facial expression from being nasty to being afraid to be destroyed. The closer the user is to the target duration, the more germs are being washed away and killed. Whenever a germ is killed, an auditive feedback is given and an animation adding a point to the total score is shown. If users stop washing their hands before destroying all germs, the remaining germs start looking angry (see

[2] https://github.com/m-altmeyer/GermDestroyer/, last accessed July 17, 2019

Figure 4. The idle-screen shows a hand washing animation to indicate that the system can be interacted with by washing one's hands.

Figure 3b) to motivate users to keep on washing hands. The amount of germs killed by the user through washing is counted and visualized in the app. During the 20-seconds-long hand washing phase, eight germs are being killed (one germ each 2.5 seconds). Figure 3c shows the screen when washing hands. To further encourage users to meet the recommended duration, the total amount of killed germs by all users today is visualized in every screen of the app, thus providing normative feedback to the users (**D5**, **D7**). Once the user has finished washing their hands, the app visualizes how many germs have been killed by the user and adds these to the total amount of killed germs per day. Also, an animation is shown visualizing clean hands indicated by sparkles and supported by a positive auditive feedback (see Figure 3d). The idle screen visualizes the total amount of killed germs and repeatedly shows an animation to indicate that the system can be interacted with by hand washing, as can be seen in Figure 4. Independent of the current screen, an overlay visualizes whether water is running and whether hands are detected or not (indicated by an icon showing washing hands or a dripping water tap respectively in the upper left corner). We implemented the app using the Unity 3D engine, deployed it on a tablet device and laser-cut a stand holding the tablet for the user studies (see Figure 1).

EVALUATION

We investigate the following hypotheses:

H1: Hand washing is more enjoyable with Germ Destroyer

H2: Hand washing for 20 seconds *seems* shorter to participants when using Germ Destroyer

H3: Germ Destroyer increases the hand washing duration

H4: Germ Destroyer increases the amount of hand washing sessions meeting the recommended duration

H5: The amount of bacteria or fungal cells, estimated by the number of colony-forming units ("CFU") on the door handle of the bathroom is lower when using Germ Destroyer

H1 is a prerequisite for the system's success in changing the behavior of users. We expect that the use of game elements such as points, normative feedback, progression and the presence of virtual characters makes hand washing more enjoyable, since previous gamified systems have been shown to be successful in this regard [27]. To investigate **H1**, we performed a user study assessing the enjoyment of the system using validated questionnaires. **H2** builds on **H1** as we expect that the increased enjoyment makes hand washing less boring and thus decreases the perceived hand washing time. **H3** is based on related work showing that gamified systems have been successful in changing people's behavior positively [15]. Thus, we expect that the use of our gamified application leads to an increase in the hand washing duration of users. **H4** targets the amount of hand washing sessions meeting the recommended duration of 20 seconds. As our gamified app takes 20 seconds of hand washing time to be completed, we expect that the amount of hand washing sessions meeting this duration should be higher when using the system. **H5** builds on **H3** as related work has demonstrated that the duration of hand washing is one of the most important factors to remove bacteria and other microorganisms [5, 28]. While **H1** and **H2** were studied in the lab, **H3, H4** and **H5** were investigated as part of an in-the-wild study, in which we installed our system in a shared bathroom for ten days and analyzed the hand washing duration. Additionally, we monitored microbiological hygiene of the bathroom's door handle by using commercially available test slides. In the next section, we present the method, procedure and results of the two studies we have conducted.

User Experience of the System

To investigate whether our system provides an enjoyable experience (**H1**), we performed a lab study, in which participants were instructed to wash their hands with and without our system using a within-subjects design.

Method

After obtaining informed consent and answering demographic questions as well as questions concerning game experience (on 5-point Likert scales), participants were instructed to wash their hands twice – once without Germ Destroyer and once with Germ Destroyer. The order of the two conditions was counterbalanced using a Latin Square design. In the baseline condition, participants were instructed to wash their hands until they were told to stop by a researcher. In the test condition, participants were asked to wash their hands until all germs within the gamified app were destroyed. In both conditions, one researcher was present and the hand washing duration was the recommended 20 seconds. Participants had to fill out questionnaires after each hand washing session. More specifically, participants were asked to answer the validated short German version of the Intrinsic Motivation Inventory [30] ("IMI"), consisting of four sub-scales: Enjoyment, Competence, Choice and Pressure. Furthermore, participants were asked to fill out the validated German version of the Positive and Negative Affect Schedule [6] ("PANAS") in order to measure whether Germ Destroyer had any effects on positive or negative affect. Afterwards, participants had to estimate how long they had been washing their hands. This was done to investigate whether the presence of the gamified app had any influence on the perceived duration. We expected that the gamified application would entertain and engage users, which would make the long hand washing duration of 20 seconds appear shorter. Results were analyzed using paired t-tests between both conditions.

Results

	Scale Range	Baseline	Test
IMI Competence	*1-15*	M=10.21 SD=2.01	M=11.43 SD=1.91
IMI Choice	*1-15*	M=12.86 SD=2.57	M=12.71 SD=1.98
IMI Pressure	*1-15*	M=5.57 SD=1.70	M=5.71 SD=3.00
IMI Enjoyment	*1-15*	M=5.93 SD=2.20	M=11.64 SD=2.06
PANAS Pos. Affect	*1-5*	M=2.19 SD=0.81	M=3.55 SD=0.51
PANAS Neg. Affect	*1-5*	M=1.13 SD=0.22	M=1.24 SD=0.36
Perceived Duration	*[in seconds]*	M=27.64 SD=13.04	M=22.14 SD=7.41

Table 1. Mean ("M") and standard deviation ("SD") for each dependent variable. Significant differences (p<.05) between conditions are colored green.

We recruited 14 participants (6 male, 8 female; 50.0% were aged 18-24, 28.6% 25-31 years, 7.1% 32-38, 7.1% 46-52 and 7.1% 53-59). Participants considered themselves gaming-affine (M = 3.36, SD = 1.15), claimed to frequently play video games (M = 3.36, SD = 1.45) and to have a passion for them (M = 3.07, SD = 1.49). Table 1 summarizes all results of this study. Results from the IMI show no significant differences concerning the sub-scales competence, choice and pressure. However, as expected, a strong significant effect was found for the enjoyment sub-scale (t(13)=-7.26, p<0.001, d=2.68). Here, the mean score roughly doubled from 5.93 without Germ Destroyer to 11.64 when using the system. Regarding the negative affect as measured by the PANAS, we could not find significant differences. However, complementing the findings for the IMI, we found a strong significant increase in positive affect, rising from a mean score of 2.19 in the baseline to 3.55 when using Germ Destroyer (t(13)=-6.42, p<0.001, d=2.01). Considering both the significant increases in the IMI enjoyment score and in the PANAS positive affect score, we conclude that Germ Destroyer positively influenced the user experience during hand washing, supporting **H1**: *Hand washing is more enjoyable with Germ Destroyer*. Since washing one's hands for the recommended 20 seconds takes much longer than people usually wash their hands [5], we aimed at decreasing the *perceived* hand washing duration (**H2**). Indeed, we found that participants estimated to have washed their hands for significantly longer in the baseline condition, i.e. without using Germ Destroyer (t(13)=2.44, p<0.05, d=0.52), even though they washed their hands for exactly the same amount of time in both conditions. This supports **H2**: *Hand washing for 20 seconds seems shorter to participants when using Germ Destroyer*.

In-the-Wild Study

To investigate **H3, H4** and **H5**, we installed our system for ten days in a shared bathroom of a company. The bathroom was located on the first floor with approximately 30 employees having their offices nearby.

Method

The first five days were used to establish a baseline using the measuring device only, while the gamified mobile app was installed additionally for the last five days. In both conditions, we stored information about whether water was running or not, whether hands were being washed and the microbial concentration of the restroom's door handle. The system was in place between 8am and 3pm, i.e. for 7 hours per day. Each morning, the door handle was disinfected to ensure comparability. The microbial concentration on the restroom's door handle was assessed at 3pm each day using mikrocount TPC slides[3]. The slides were incubated at 37° Celsius for 24 hours. Afterwards, the test slides were photographed and the number of CFUs was counted. The study was approved by our ethical review board[4] and thoroughly discussed with the company's data protection officer and its employee representatives. Since the data protection officer raised concerns about installing the system in the women's restroom (the low number of women having their offices nearby would potentially allow one to infer who was using the bathroom), we decided to test the system in the men's bathroom only. Given that literature has shown that men neglect hand washing much more than women [19], we see this as acceptable. Due to the anonymous data collection, all three parties involved approved the execution of the study.

Results

Overall, 363 hand washing sessions were recorded throughout the study (36.30 per day on average, SD=7.17) with a mean duration of 7.64 seconds (SD=7.11 seconds). In the baseline phase (days 1–5), 161 hand washes were recorded (32.20 per day on average, SD=6.26) having a mean hand washing duration of 5.56 seconds (SD=4.99 seconds). In the intervention phase, i.e. after installing Germ Destroyer (days 6–10), the amount of hand washing sessions increased to 202 (40.4 per day on average, SD=5.86). Also, the mean hand washing duration strongly increased to 9.30 seconds (SD=8.07 seconds). As revealed by a Welch's t-test (the assumption of homogeneity of variance was violated), this increase is significant (t(341.24)=-5.43, p<0.001, d=0.54). This provides strong evidence for **H3**: *Germ Destroyer increases the hand washing duration*. Figure 5 visualizes the average hand washing duration and the standard deviation for all days of the study separately.

In the baseline phase, only 1.86% (SD=13.57%) of hand washing sessions were at least 20 seconds long. When relaxing this to a duration of 15 seconds (which is the lower bound of the recommended hand washing time [18]), the amount of hand washing sessions meeting this criterion climbs up to 3.73% (SD=19.00%). In the intervention phase these results change substantially. The amount of hand washing

[3] https://www.schuelke.com/intl-en/products/mikrocount-TPC.php, last accessed July 17, 2019

[4] https://erb.cs.uni-saarland.de/, last accessed July 17, 2019

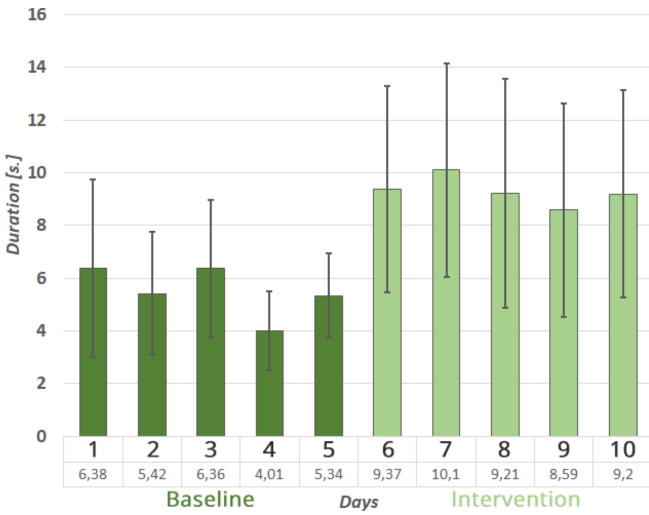

Figure 5. Average hand washing duration in seconds for each day of the study. The baseline phase was from day 1–5 (dark green), the intervention phase from day 6–10 (light green).

sessions lasting at least 20 seconds significantly increased to 17.82% (SD=38.37%; t(260.94)=-5.50, p<0.001, d=0.53). When relaxing this again to 15 seconds, the amount of hand washing events having at least this length increases significantly to 26.73% (SD=44.37%; t(285.18)=-6.65, p<0.001, d=0.65). Therefore, **H4**: *Germ Destroyer increases the amount of hand washing sessions meeting the recommended duration* is supported.

Since the door handle of the bathroom is most likely touched by all people using it and thus provides an increased risk of infection, we analyzed the bacteria count on it. The results were discussed with a microbiologist and a pharmacist. Since we only have five measurements (one measurement per day) per study phase and because the data was not normally distributed, we used the non-parametric Mann-Whitney-U test to compare the amount of CFUs. In the baseline phase, we counted 90.40 CFUs per test slide on average (SD=67.67, Median=79.00, Min=27, Max=204). In the intervention phase, the number of CFUs declined significantly (U=3.00, Z=-1.98, p<0.05, r=0.63) to 33.60 on average (SD=22.19, Median=21.00, Min=14, Max=62). These results support evidence for **H5**: *The amount of colony-forming units ("CFU") on the door handle of the bathroom is lower when using Germ Destroyer*. Figure 6 shows the CFU counts and pictures of the test slides after incubation for each day.

Discussion

In the course of a lab-based and an in-the-wild study we investigated the user experience and the effectiveness of our system. We found that Germ Destroyer makes hand washing more enjoyable and that people experience a more positive affect when using the system (**H1**). We assume that these positive effects are explainable by the gameful feedback provided by the system. More specifically, we suppose that gamification elements such as progression, points, virtual characters and praise lead to the increase in the IMI enjoyment as well as in the PANAS positive affect sub-scale since similar results have been reported in literature in different health-related contexts [16, 27]. The fact that participants perceived the hand washing time as shorter when using Germ Destroyer (**H2**) is most likely a direct consequence of the increased enjoyment [29] and thus supports **H1** further. Additionally, this finding shows that people tend to overestimate their time spent washing hands, which might explain the short hand washing duration found in the baseline phase of our in-the-wild study and in literature. The aforementioned evidence we found supporting both **H1** and **H2** forms the basis to find positive effects on hand washing behavior in the in-the-wild study.

Here, we found that the hand washing time in the baseline phase is far below the recommended duration of 20 seconds, with participants washing their hands for 5.56 seconds on average. This duration is in line with observational studies reporting that most people wash their hands for about 4-7 seconds [5, 28]. Additionally, the amount of people washing hands for at least 15 seconds (3.73%) or 20 seconds (1.86%) is in line with previous research reporting that roughly 5% washed their hands longer than 15 seconds [5]. In view of these results, our measurement approach and our sample population seem appropriate. In the intervention phase (when Germ Destroyer was installed in the bathroom) both measures significantly increased (**H3, H4**). While the mean washing duration almost doubled, the amount of people washing their hands for more than 20 seconds even approached a tenfold increase. These results show clearly that the presence of our system had a strong positive effect on the hand washing time. Potential reasons for these effects include an increased awareness caused by the application as was reported in [3], the higher enjoyment of hand washing (**H1, H2**), receiving gameful feedback and praise [13] or simulating the decrease of contamination using germs as virtual characters [10, 13]. The analysis of CFUs revealed that there were fewer viable bacteria or fungal cells when using Germ Destroyer (**H5**). One reason for this decrease could be the longer hand washing duration. Considering that the number of hand washing events was higher in the intervention phase, another reason could be that that the number of people who did not wash their hands at all was lower in the intervention phase. This would be in line with research showing that 33% usually do not wash their hands in shared bathrooms [31].

Limitations

First, the in-the-wild study was conducted in the men's bathroom only. This was due to ethical concerns of the data protection officer, since the low number of women having their offices nearby would allow one to infer who was using the bathroom and when. Therefore, even though both men and women appreciated the system in the user experience lab study and no gender effects were found, it is not clear whether installing the system in the women's bathroom would lead to similar results. Given previous literature consistently reporting that men wash their hands less than women [5], we would expect that the effect might be smaller in the women's bathroom. It should also be noted that the system has been evaluated in a company – testing the system in different environments

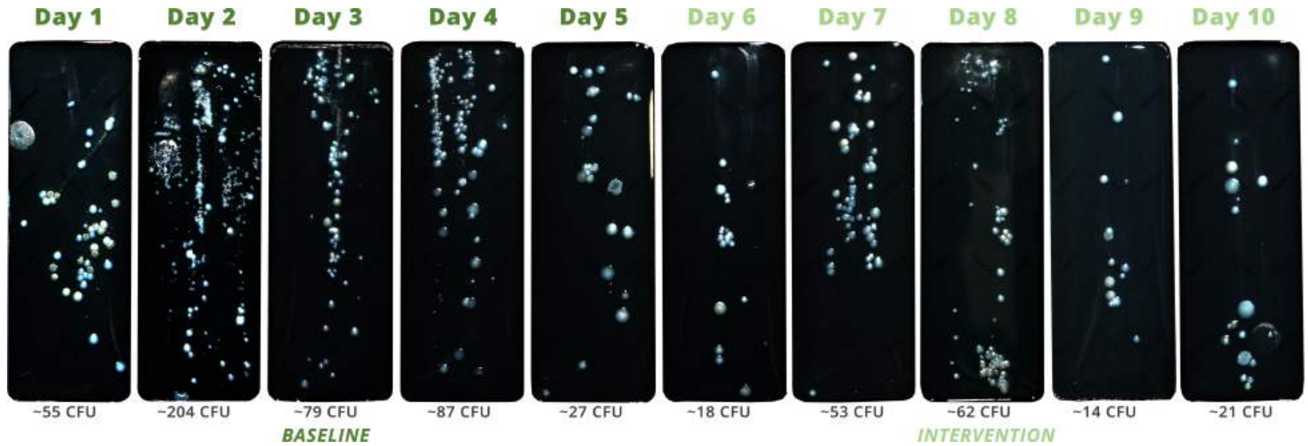

Figure 6. Pictures of the mikrocount TPC test slides after 24 hours incubation at 37° Celsius and the number of colony-forming units for each day. Days 1–5 belong to the baseline phase while Germ Destroyer was in place during days 6–10.

could lead to different effects. Although the results obtained as part of the in-the-wild study align well with previous literature, we would like to acknowledge that we cannot rule out measuring errors of our device. Due to the anonymous data collection, which was necessary so as to not violate the privacy of participants, we cannot give concrete information about the absolute number of discrete participants during the in-the-wild test. Considering that men use the bathroom 4.8 times during an 18-hour day on average [7] and thus assuming that people go to the bathroom one to two times between 8am and 3pm, we expect to have had 18–24 distinct users per day. This is supported by the number of offices nearby, as stated in the method section. It should also be noted that the duration of the in-the-wild study was not sufficient to make a statement about the long-term success of the system. Also, the potentially increased water consumption should be considered, especially when using our system in regions with water scarcity. Lastly, the measurement of the number of CFUs per day on the door handle has limitations. People possibly touching other things (like their face) between washing their hands and leaving the bathroom might confound a direct effect between the system and the bacterial counts. Also, the type of bacteria is unknown, i.e. it is unclear whether these bacteria are related to the use of the bathroom or are typical for human hands. Therefore, the results related to the bacterial counts on the door handle should not be overstated and need further validation.

CONCLUSION AND FUTURE WORK

We presented Germ Destroyer, a gameful, unattended and open-source system to encourage people to wash their hands for the recommended duration of 20 seconds. We contributed the system design, including access to all parts of the system making it possible to easily re-create the system and use it for future interventions. The evaluation of the system shows that it has positive effects on the enjoyment of hand washing, reduces the *perceived* washing duration, and at the same time effectively motivates people to wash their hands for a longer time. We also showed that Germ Destroyer not only encourages people to meet the recommended hand washing duration but also seems to decrease the risk of infection in shared bathrooms. Taking these findings together, Germ Destroyer has the potential to contribute to improving public and personal health.

Future work includes testing whether similar behavioral effects can be replicated with a female sample and whether the results we found still hold over a longer study duration. Also, extending the system to recognize hand washing quality seems interesting, although realization without using camera-based approaches might be difficult. Lastly, investigating suitable game concepts for different age groups and different contexts (e.g. nursing homes, elementary schools) or altering the way feedback is provided (similar to [17]) seems to be worthwhile to consider.

ACKNOWLEDGMENTS

We thank Jordan Espenshade and Nina Thewes for their advice in analyzing and interpreting results related to the microbial concentration of the restroom's door handle.

REFERENCES

[1] Allison E Aiello, Rebecca M Coulborn, Vanessa Perez, and Elaine L Larson. 2008. Effect of Hand Hygiene on Infectious Disease Risk in the Community Setting: A Meta-Analysis. *American Journal of Public Health* 98, 8 (2008), 1372–1381. DOI: `http://dx.doi.org/10.2105/AJPH.2007.124610`

[2] Maximilian Altmeyer, Pascal Lessel, Tobias Sander, and Antonio Krüger. 2018. Extending a Gamified Mobile App with a Public Display to Encourage Walking. *Proceedings of the 22nd International Academic Mindtrek Conference on - Mindtrek '18* (2018), 20–29. DOI: `http://dx.doi.org/10.1145/3275116.3275135`

[3] Toshiko Asai, Akinori Kanazawa, Hidehiko Hayashi, and Akinori Minazuki. 2013. Development of a System to Raise Awareness of Hand Hygiene in Various Environments. *Proceedings - 2013 International Conference on Signal-Image Technology and Internet-Based Systems, SITIS 2013* (2013), 924–931. DOI: `http://dx.doi.org/10.1109/SITIS.2013.150`

[4] Leonardo Bonanni, Ernesto Arroyo, Chia-Hsun Lee, and Ted Selker. 2005. Exploring Feedback and Persuasive Techniques at the Sink. *Interactions* 12, 4 (2005), 25. DOI:http://dx.doi.org/10.1145/1070960.1070980

[5] Carl P Borchgrevink, JaeMin Cha, and SeungHyun Kim. 2013. Hand Washing Practices in a College Town Environment. *Journal of environmental health* 75, 8 (2013), 18–24. DOI: http://dx.doi.org/10.1177/1352458514549395

[6] B. Breyer and M. Bluemke. 2016. Deutsche Version der Positive and Negative Affect Schedule PANAS (GESIS Panel). *Zusammenstellung sozialwissenschaftlicher Items und Skalen* March (2016). DOI: http://dx.doi.org/10.6102/zis242

[7] Kathryn L. Burgio, Bernard T. Engel, and Julie L. Locher. 1991. Normative Patterns of Diurnal Urination Across 6 Age Decades. *The Journal of Urology* (1991), 728–731.

[8] Centers for Disease Control and Prevention. 2018. How to Wash Your Hands. (2018). https://www.cdc.gov/features/handwashing/index.html

[9] Francesco Corato, Maria Frucci, and Gabriella Sanniti Di Baja. 2012. Virtual Training of Surgery Staff for Hand Washing Procedure. *Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '12)* (2012), 274. DOI: http://dx.doi.org/10.1145/2254556.2254608

[10] Val Curtis, Wolf Schmidt, Stephen Luby, Rocio Florez, Ousmane Touré, and Adam Biran. 2011. Hygiene: New Hopes, New Horizons. *The Lancet Infectious Diseases* 11, 4 (2011), 312–321. DOI: http://dx.doi.org/10.1016/S1473-3099(10)70224-3

[11] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. 2011. From Game Design Elements to Gamefulness: Defining Gamification. *Proceedings of the 15th International Academic MindTrek Conference. ACM, 2011.* (2011), 9–15. DOI: http://dx.doi.org/10.1145/2181037.2181040

[12] Regina I Ejemot, John E Ehiri, Martin M Meremikwu, and Julia A Critchley. 2009. Cochrane Review: Hand Washing for Preventing Diarrhoea. *Evidence-Based Child Health: A Cochrane Review Journal* 4, 2 (2009), 893–939. DOI:http://dx.doi.org/10.1002/ebch.373

[13] B J Fogg. 2002. *Persuasive Technology: Using Computers to Change What We Think and Do*. Morgan Kaufmann Publishers. DOI: http://dx.doi.org/10.1145/764008.763957

[14] Maryellen E Guinan, Maryanne Mcguckin-guinan, and M T Ascp. 1997. Who Washes Hands After Using the Bathroom? *American Journal of Infection Control* 35 (1997), 5–6.

[15] Juho Hamari, Jonna Koivisto, and Tuomas Pakkanen. 2014. Do Persuasive Technologies Persuade? - A Review of Empirical Studies. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 8462 LNCS (2014), 118–136. DOI: http://dx.doi.org/10.1007/978-3-319-07127-5_11

[16] Juho Hamari and Harri Sarsa. 2014. Does Gamification Work? - A Literature Review of Empirical Studies on Gamification. *Hawaii International Conference on System Sciences.* (2014), 3025–3034. DOI: http://dx.doi.org/10.1109/HICSS.2014.377

[17] Chris Harrison, Zhiquan Yeo, and Scott E Hudson. 2010. Faster Progress Bars: Manipulating Perceived Duration with Visual Augmentations. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2010), 1545–1548. http://chrisharrison.net/projects/progressbars2/ProgressBarsHarrison.pdf

[18] Dane A. Jensen, Michelle D. Danyluk, Linda J. Harris, and Donald W. Schaffner. 2015. Quantifying the Effect of Hand Wash Duration, Soap Use, Ground Beef Debris, and Drying Methods on the Removal of Enterobacter aerogenes on Hands. *Journal of Food Protection* 78, 4 (2015), 685–690. DOI: http://dx.doi.org/10.4315/0362-028x.jfp-14-245

[19] Durell Johnson, Danielle Sholcosky, Karen Gabello, Robert Ragni, and Nicole Ogonosky. 2005. Sex Differences in Public Restroom Handwashing Behavior Associated with Visual Behavior Prompts. *Perceptual and Motor Skills* 97, 7 (2005), 805. DOI: http://dx.doi.org/10.2466/pms.97.7.805-810

[20] Dana E. King, Arch G. Mainous, Mark Carnemolla, and Charles J. Everett. 2009. Adherence to Healthy Lifestyle Habits in US Adults, 1988-2006. *American Journal of Medicine* 122, 6 (2009), 528–534. DOI: http://dx.doi.org/10.1016/j.amjmed.2008.11.013

[21] Andrea Kinnison, Randal R. Cottrell, and Keith A. Ki. 2004. Proper Hand-Washing Techniques in Public Restrooms: Differences in Gender, Race, Signage, and Time of Day. *American Journal of Health Education* 35, 2 (2004), 86–89. DOI: http://dx.doi.org/10.1080/19325037.2004.10603614

[22] Pascal Lessel, Maximilian Altmeyer, Frederic Kerber, Michael Barz, Cornelius. Leidinger, and Antonio Krüger. 2016. WaterCoaster: A Device to Encourage People in a Playful Fashion to Reach Their Daily Water Intake Level. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems. ACM* 07-12-May- (2016), 1813–1820. DOI: http://dx.doi.org/10.1145/2851581.2892498

[23] Md Abu Sayeed Mondol and John A. Stankovic. 2015. Harmony: A Hand Wash Monitoring and Reminder System using Smart Watches. *EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services* (2015). DOI: http://dx.doi.org/10.4108/eai.22-7-2015.2260042

[24] Elizabeth Monk-Turner, Stephen Warren, Donald Edwards, Maria Rushing, Steve Poorman, and Jaritha Willie. 2006. Predictors of Hand-Washing Behavior. *Social Behavior and Personality: An international Journal* 30, 8 (2006), 751–756. DOI: http://dx.doi.org/10.2224/sbp.2002.30.8.751

[25] David P Nalbone, Kevin P. Lee, Amanda R. Suroviak, and Jennifer M. Lannon. 2005. The Effects of Social Norms on Male Hygiene. *Individual Differences Research* 3, 3 (2005), 171–176.

[26] Chris Schaefbauer, Danish Kahn, Amy Le, Garrett Sczechowski, and Katie Siek. 2015. Snack Buddy: Supporting Healthy Snacking in Low Socioeconomic Status Families. *Computer Supported Cooperative Work and Social Computing (CSCW)* (2015), 1045–1057.

[27] Katie Seaborn and Deborah Fels. 2015. Gamification in Theory and Action: A Survey. *International Journal of Human-Computer Studies* 74 (2015), 14–31. DOI: http://dx.doi.org/10.1016/j.ijhcs.2014.09.006

[28] Debra Smith, Barry S. Michaels, Charles A. Bartleson, Judy D. Greid, and Ewen C. D. Todd. 2016. Outbreaks Where Food Workers Have Been Implicated in the Spread of Foodborne Disease. Part 9. Washing and Drying of Hands To Reduce Microbial Contamination. *Journal of Food Protection* 73, 10 (2016), 1937–1955. DOI:http://dx.doi.org/10.4315/0362-028x-73.10.1937

[29] Simon Tobin and Simon Grondin. 2009. Video Games and the Perception of Very Long Durations by Adolescents. *Computers in Human Behavior* 25, 2 (2009), 554–559. DOI: http://dx.doi.org/10.1016/j.chb.2008.12.002

[30] M. Wilde, K. Bätz, A. Kovaleva, and D. Urhahne. 2009. Testing a Short Scale of Intrinsic Motivation. *Zeitschrift für Didaktik der Naturwissenschaften* 15 (2009), 31–45.

[31] Wirthlin Worldwide Research and Bayer Pharmaceutical Division. 1996. Handwashing Survey. Fact Sheet. Distributed at American Society for Microbiology Annual Meeting, New Orleans. (1996).