Bringing Healthcare-Level Hand Hygiene Skills to Children Through Iterative App Design

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Abstract: Handwashing is an effective and low-cost practice that offers protection against a host of infectious diseases, both respiratory and gastrointestinal—but only when it is done at the appropriate time, with proper technique, and consistently when indicated. Public health efforts that emphasized access to clean water, soap, and towels, were combined with public messaging through flyers, posters, and videos with prompts to wash hands. Yet despite these efforts to raise awareness, the public health achievement gap has remained intractably wide. One problem is technique: teachers and parents are not commonly taught proper handwashing skills, which translates into imperfect technique being transferred to children in their care. Another is healthy habit formation: despite years of pandemic, heightened awareness, and sincere efforts by adults and children alike, durable handwashing practices have not taken hold. To address this unmet public health need, we developed an interactive digital trainer for touchscreen devices commonly found in schools and at home. Teacher co-developers, domain experts, students, and parents participated throughout the project, through rapid and frequent cycles of design, build, test, and refine. The trainer 1) conveys proper technique with accurate hand anatomy for high-fidelity learning; 2) provides critical visual feedback of germs remaining, so that players learn to use the appropriate scrub motion to address specific areas on each hand; 3) simulates infection transmission schoolwide, for experiential learning on when handwashing is indicated; 4) fosters habit formation, over several sessions, for lifelong gains in hand hygiene. This approach to game design, development, and evaluation was critical to the success of this project and is broadly applicable to many other learning domains.

Keywords: Game design for education, Serious games for skill development, Mobile and tablet games, Interactive simulations, Games for public health

1. Introduction

While healthcare has been highly effective in diagnosing and treating disease, the final and missing link has been improving healthy behaviour in individuals. Clean water and sanitary sewer systems have greatly reduced the transmission of many common diseases, but the "last kilometre" of public health is individual behaviour. Where vaccines and masks have proved controversial, handwashing has been spared the intense political debates that have surrounded other public health measures. Handwashing remains cheap, and if performed correctly, very effective in reducing the transmission of a host of diseases, including the common cold, influenza, and polio.

Notably lacking in the worldwide public campaign to wash hands, and the expensive installation of handwashing stations and signage, was *effective training in technique*. To address this unmet need, we developed an interactive hand hygiene learning game (the *Bubble Beats Trainer* 2025), for children and adults, to teach how to wash, when to wash, and foster consistent practice. We set a very high benchmark for success, with the following design features:

- the training must be engaging
- the training must have high fidelity to real-world practice
- the training must be to a high standard

Interactive digital media training in *effective technique* has not been commercially available. For students, only low-fidelity simulation training has been assessed (Lee 2015, 2022). Fidelity to real-world behaviour is crucial to effective training and may explain the less-than-stellar improvements yielded from these approaches. Two studies *simplified the training* to an abbreviated hand washing procedure (Younie 2020, Lee 2022). One study used *video* examples of handwashing, was therefore not interactive (Lee 2022). Computer vision systems to identify handwashing motion are engaging, but low-fidelity, and often error prone (Kang 2019).

2. Design Choices and Trade-Offs

2.1 High Engagement: Capture Players' Attention, and Reward Their Participation

Creating an entertaining and accurate learning game about hand hygiene is not trivial. An important learning goal is systematic and thorough handwashing. Inducing the player to perform handwashing again and again is about as engaging as practicing musical scales on a violin. But practicing musical scales opens the door to a world of expressive music, but practicing handwashing simply leads to more handwashing. For good game design, many of the features we would expect to be present are lacking, as shown below in Table 1.

Table 1: Engaging games have features that real-world handwashing lacks

	Engaging Games	Real-world Handwashing
Activity	Varied	Repetitive
Visual Feedback	Often Immediate	Almost None
Learning Curve	Rising	Plateau
Strategy/Tactics	Frequently Vital	Absent

Table 1 illustrates how effective handwashing may be an important skill, but the training to wash hands at the sink does not immediately translate into an engaging game. Nevertheless, a good learning game design should resist the temptation to make a more engaging game in ways that harm the learning. One game (Sponge 2016) turned the handwashing activity into a chase across the hands: players moved a scrubbing cursor to capture a moving bug. Although pursuit is naturally engaging, the portrayal of accurate scrubbing suffers.

Adding visual feedback is another challenge, because in real life, germs are invisible without magnification and/or special dyes and illumination. Making them visible, or compressing the time between pathogen exposure to development of symptoms (SureWash 2024), risks sending the wrong message to the player. In real life, contaminated hands do not show creatures the size of small insects. In real life, it takes hours or days to incubate an infection. A player's own day-to-day experiences will contradict this message. Conversely, the message may prove to be *too effective*, encouraging unwanted phobias.

Finally, when presenting scenarios to a player, to learn when handwashing is indicated, the answer should not always be the same: *wash your hands*. To hold a player's interest, the game should provide *variety* in the activity, an increasing learning curve of *challenge* commensurate with the player's improving skill and involve some *planning* or *goal setting* through strategy or tactics for long-lasting engagement.

2.2 How to Wash: Efficient Visuomotor Transfer of Handwashing Technique

Figure 2: Hand anatomy is not a priority in these screenshots of popular handwashing demonstrations: (1) Sesame Street: Washy Wash Song, (2) Baby Shark Wash Your Hands, (3) Wash Hands reminder tracker, (4) Ellie's Hand Wash Adventure. A handwashing learning game that does not portray hands accurately, but instead shows static, flat artwork, is a missed opportunity to demonstrate proper technique

To foster good handwashing technique, the learning game should above all depict hand anatomy *accurately*. One severe shortcoming of existing learning games has been the use of cartoon-style hands. These simplified, two-dimensional representations fail to model the scrubbing motions needed for effective handwashing. In other contexts (Sharmin 2023), learners have struggled with the cognitive load to visualize 3D structures when presented only 2D representations. Accurate spatial representation (Hegarty 2011) can reduce this cognitive load (Ishikawa 2021).

For all players, including children, we chose the hand hygiene standard for healthcare workers (World Health Organization, 2009). Mere depiction of accurate anatomy is not sufficient, however. The player must participate in the manipulation of these 3D rendered hands.

For training in handwashing, augmented or virtual reality would be ideal. But the practical problems of implementing this technology are significant. One app (SureWash 2020) uses computer vision with augmented reality to train and assess whether learners are performing handwash scrub moves correctly. However, consumer-grade computer vision is still evolving. Rear facing cameras on smartphones and tablets are almost always superior to those facing forward and embedded in the display. On higher-end phones, rear-facing cameras may also be accompanied with depth-sensing scanners. Unfortunately, apps are limited to using the front-facing cameras when the user needs to interact with the screen at the same time the camera is in use. As a result, smartphones and tablets have difficulty resolving the positions of two hands with intertwined fingers. Finally, the number of virtual reality and augmented reality systems remains vanishingly small, compared to devices with touchscreens—especially in schools.

For these reasons, we chose to develop 3D animations of hands that would work on 2D devices with touchscreens, without special use of cameras.

2.3 Practical Endpoint: target Behaviour Change in the Real World

Designing a highly engaging game is by itself a challenge. More difficult is designing a learning game that holds the player's attention and delivers learning games. Still more difficult is a game for health: one that improves real-life behaviour that results in healthy outcomes (Verschueren 2019, Thompson 2010). Just how these behaviours can be changed through game play is a matter of debate (Baranowski 2016), with several similar, overlapping, and difficult-to-reconcile theories of behaviour (Noar 2005, Sheeran 2017). Many of these health behaviour models describe a *mediator* (MacKinnon 2011, Schwarzer 2008), or intermediate factor that influences health status. For example, a prevention program may target changing social norms (the mediator) to reduce tobacco use (MacKinnon 2002).

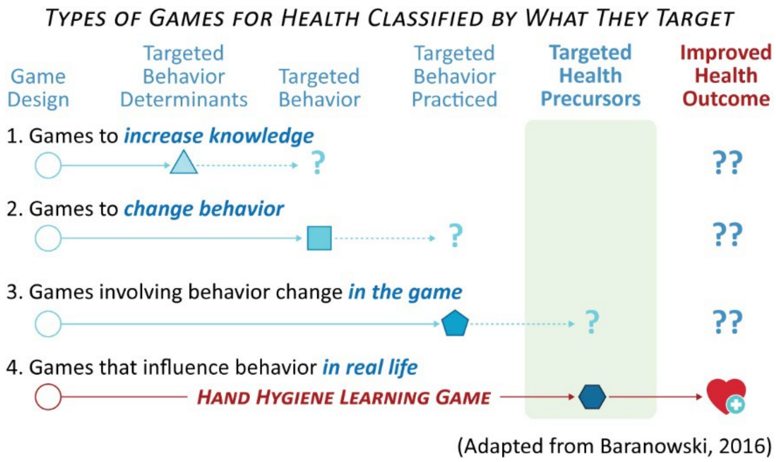


Figure 2: Games for health can be classified by how closely associated they are with the desired health outcome. The closer the game is to the health outcome, the stronger the association. For our hand hygiene learning game, the targeted health precursor will be effective handwashing, demonstrated by players, at the sink

Baranowski (2016) and others (Thompson 2007) have used the mediator of *self-efficacy* (Bandura 1998) to build games that manage childhood obesity and type-II diabetes in vulnerable populations, by encouraging players to regulate calorie intake. Others have built games that intervene in the days before a surgical procedure, or the onset of chemotherapy, to reduce anxiety and other *targeted health precursors* to improve medical outcomes: these acute interventions have resulted in more positive attitudes toward therapy and have even reduced hospital stays.

Baranowski classifies Games for Health into 4 types (Figure 2), with increasing penetration into the chain of events that influence health status. Type 1 games merely increase knowledge and have the weakest association with desired health status. Type 2 games attempt to change behaviour outside of the game. Type 3 games attempt to change this behaviour both inside and outside the game. Type 4 games intervene most closely to the desired health outcome, have the strongest association, and the highest likelihood of successful behaviour change.

For the hand hygiene learning game, effective health behaviour change would use the endpoints of improved handwashing technique with an external, quantitative assay. It is superior to a Type 1 game, because it does more than increase the student's knowledge about handwashing. Because accurate handwashing is practiced and assessed both in the game as well as in real life, the learning game fulfils the criteria for a Type 2 and Type 3 game. Finally, because the learning game addresses a targeted health precursor to transmissible disease (hand hygiene) it has the potential to be a Type 4 game, the most powerful association with improved health status.

2.4 Interactive and Responsive: Provide Critical Visual Feedback to the Player

The challenge of teaching effective handwashing is the lack of critical visual feedback. Neither a parent nor a child can tell, merely by looking, whether the hands have been cleaned. Without visible evidence of what was cleaned and what was missed, a student may never practice handwashing correctly, even if highly motivated to do so.

There is, however, a helpful workaround when demonstrating handwashing in person: hand lotion with invisible dye that glows brightly under ultraviolet light (Glo Germ). Once applied, the dye cannot be seen on the hands. It is removed by thorough scrubbing with soap and water. After washing, inspection of the hands under ultraviolet (UV) illumination reveals bright fluorescent areas that were missed.

Therefore, we planned to emulate this experience in the learning game: players would wash the virtual hands, but would receive no visual feedback on their progress. Only after deciding that washing was finished, could they inspect their hands, using a virtual UV light that would highlight areas that were not completely washed.

2.5 When to Wash: Players Should Discover for Themselves When Handwashing is Indicated

The simplest, and most obvious way to teach players when to wash their hands is through flashcards. As Baranowski argued, however (see Figure 2), mere knowledge may not translate into real-life action. Instead, the learning game may do better to follow advice for effective writing: *show, don't tell*. This approach is the basis for *experiential learning*.

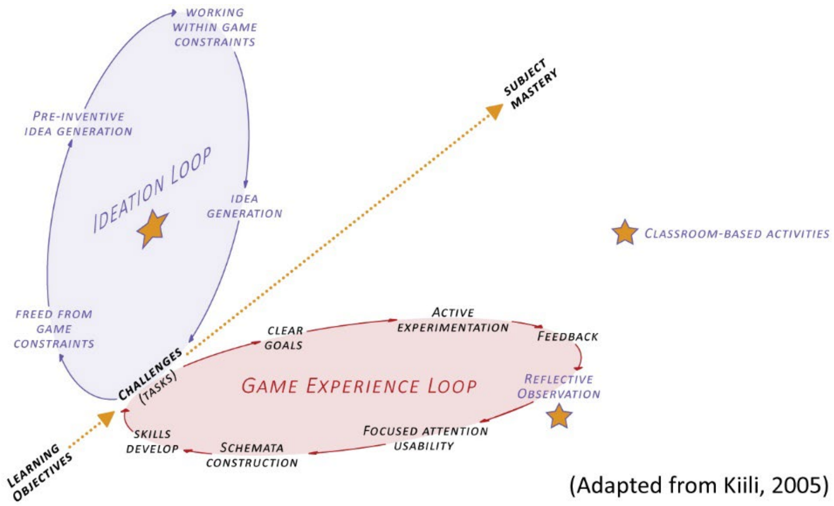


Figure 3: An experiential learning model for learning games adapted from Kiili (2005). Learning involves contributions from both direct gameplay (the game experience loop), as well as contemplation when not actively playing (the ideation loop). Good learning games embrace both—by supporting ideation, learning and memory consolidation outside the game. The game confronts players with challenges or tasks, which are overcome where these two loops meet. Progress towards subject mastery occurs when these loops function in concert

The experiential gaming model is composed of two activity loops: ideation and game experience. The ideation loop begins with free-form imagination (free of constraints otherwise imposed by the game onto the world), followed by idea generation that works within the constraints of the learning game. This cycle is the process by which players invent new models of how the game world might work; Kiili notes that this ideation cycle is best when performed in groups, such as in a classroom.

Next, players test these ideas in the game: good games have a clear goal, invite experimentation, and provide immediate feedback to the player. Reflective observation allows players to share their experiences, describing what they thought was at stake, their strategies, and the results of their choices (indeed, some of the greatest value derived from games is sharing the experiences with others). Consolidating the reflective observation may then lead to the formation of new and better solutions (schemata) which in turn may develop the player's skills to the point of steering the game to the desired outcome and subject mastery.

A learning game (or almost any computer game) can be thought of as a series of challenges served up to the player. For a learning game, these challenges stem from the learning objectives. When this system of ideation and experience loops are optimized, players are pushed into a zone of proximal development, at the edge of their competency, fully engaged, combined with immense drive to master the challenge. Harnessing this powerful engagement, and directing to mastering the targeted learning objectives, is the holy grail of game-based learning.

In the case of hand hygiene training, players should encounter scenarios where handwashing should occur. When they fail to act, they should witness pathogen transmission unfold, in a manner that mirrors actual disease. If the design is flexible, new scenarios can be added to the training, for comprehensive training on when to wash. The win state for this learning mode should be identification of these scenarios, with prompt action to wash hands.

2.6 Consistent Practice: Healthy Habit Formation for Lifelong Benefits Through Improved Hand Hygiene

Healthy habit formation for hand hygiene has been studied in healthcare workers (Al-Tawfiq 2013, Eiamsitrakoon 2013, Srigley 2015), using the theory of planned behaviour (Ajzen 1991) and the transtheoretical model of change (Prochaska 1997). We used this framework in designing our learning game, shown below in Figure 4.

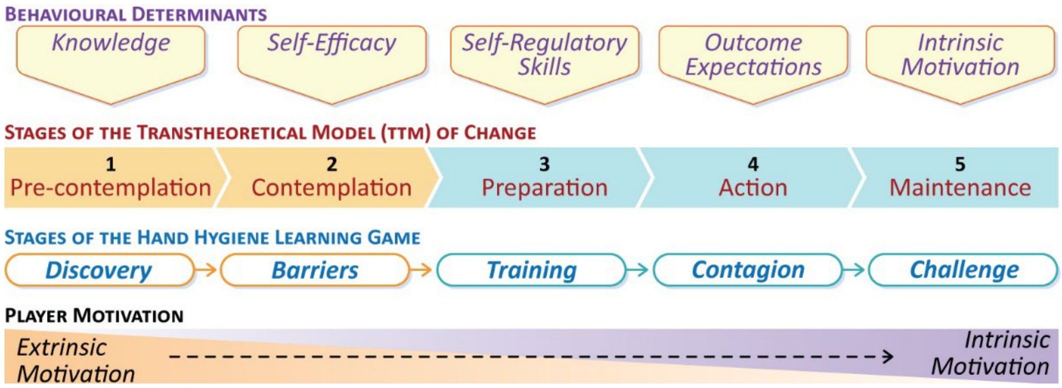


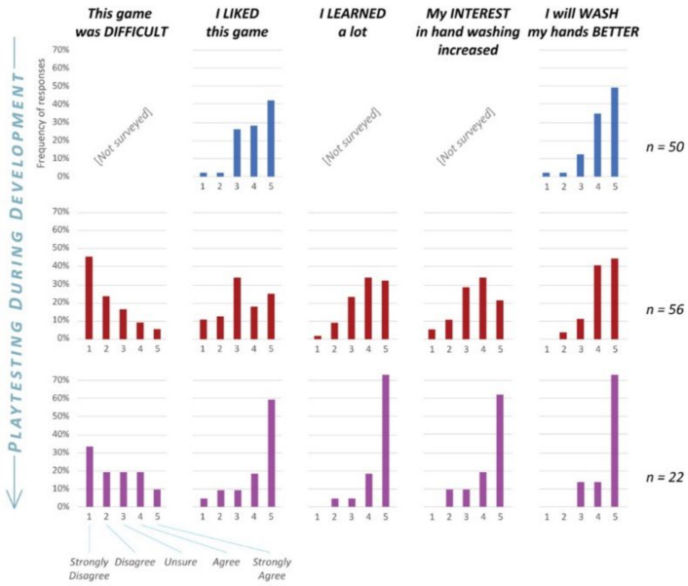
Figure 4: The hand hygiene learning game uses the Transtheoretical Model (TTM) of change (Prochaska, 1997) to migrate players, in stages, from pre-contemplation to maintenance of effective hand hygiene. Behavioural determinants (in yellow, top row) contribute to each stage of the TTM model. Like other models (Baranowski), TTM weighs pros and cons of choosing a healthy behaviour and uses self-efficacy to empower the individual to perform it. We used these insights to design stages of the hand hygiene learning game (text bubbles, third row). Finally, on the bottom row, player motivation will shift from extrinsic rewards in the game to intrinsic motivation as the player progresses through higher stages. This conceptual framework follows TTM theory—as well as good game design—to keep players engaged beyond initial superficial entertainment, to more durable and valuable achievements earned in the game

3. Playtesting Results

3.1 High Engagement

Early versions of the learning game used rhythm matching as a game mechanic: when players scrubbed in time with the music, they received higher scores, and cleaned more quickly. We discovered through gameplay that some players would happily scrub at the fastest rate they could, oblivious to the rhythm. Another significant minority of players exhibited no talent for rhythm, and became frustrated playing this version of the game.

During 3 large rounds of playtesting, involving 20 to 50 children, participants used the hand hygiene learning game on Chromebooks with touchscreens for at least 25 minutes. At the end of each level played, data were logged including level achieved, playing duration, and the number and kind of scrub steps used to complete the level. If players consulted virtual UV inspection, and then returned to a scrub step, that step was counted a second time. Players completed about 3 levels during a playtest session. Participants received a post-intervention questionnaire to evaluate the game. Qualitative responses helped guide the next iteration, by identifying features that were popular, game mechanics that were engaging, and new wash steps that players had learned from the game. Quantitative results from three rounds of playtesting are shown below in Figure 5.



	n	mean	variance
MAY: 7-11 year olds			
The game was DIFFICULT			
I LIKED this game	50	4.06	0.96
I LEARNED a lot			
My INTEREST in handwashing increased			
I will WASH my hands BETTER	49	4.27	0.82
JULY: 12-14 year olds			
The game was DIFFICULT	55	2.05	1.50
I LIKED this game	56	3.34	1.65
I LEARNED a lot	56	3.86	1.07
My INTEREST in handwashing increased	56	3.55	1.23
I will WASH my hands BETTER	54	4.26	0.65
AUGUST: 7-14 year olds			
The game was DIFFICULT	21	2.52	1.96
I LIKED this game	22	4.18	1.49
I LEARNED a lot	22	4.59	0.63
My INTEREST in handwashing increased	21	4.33	1.03
I will WASH my hands BETTER	22	4.59	0.54

Figure 5: Playtesting results from rounds in May, July, and August show progression to higher survey scores across four measures (liking the game, learning, increased interest in handwashing, and intention to wash hands better). The reported level of difficulty was appropriate: showing nearly even distribution of difficulty

3.2 How to Wash: Accurate Depiction of Anatomy for Efficient Visuomotor Transfer of Handwashing Technique

The World Health Organization (2009) describes 6 specific scrub motions, 3 of which have separate steps for left and right hands. For our training animations, we included wrists, and specified separate left and right steps for fingernails, after discovering reference videos that demonstrated these additional steps (JHU 2019).

A digital single-lens reflex camera recorded reference videos at 4K resolution from a fixed position from the player's point of view when washing hands at the sink. Existing animation models were rigged and animated using Blender, and morphed to create anatomically accurate hands of a child. The completed animation files were imported to the Unity game engine.

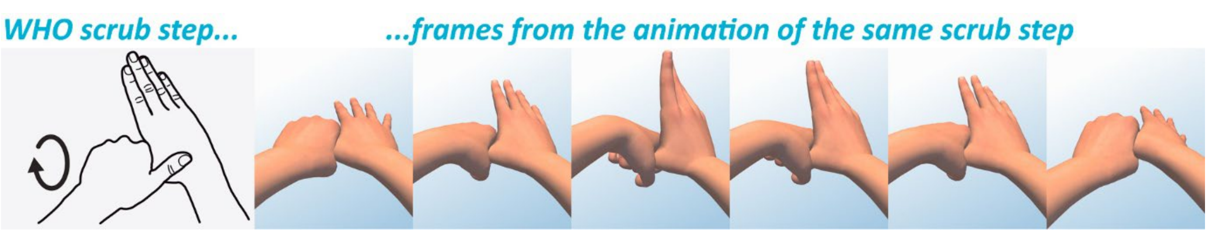


Figure 6: The line-art drawing of right thumb scrub is taken from the WHO guidelines on handwashing. In the hand hygiene learning game, this scrub step has been transformed into a high-fidelity animation based on reference videos. Player participation in moving these virtual hands through the proper scrubbing motion increases engagement, learning, and retention

Choosing a touchscreen interface allowed for a broader user base beyond virtual reality systems, but created a new problem: how could the player use a 2D surface to control hands in 3D? Bringing left and right hands together for washing involves translation along the XYZ axes, but also rotation, extension of some fingers while curling of others. For complete handwashing, there are 7 different scrub steps, 5 of them with left and right variants—for 12 steps in all.

We ran a real risk of creating a player control that was *too complex*. Fighting games solve this problem by employing only a few button inputs on game console controllers, but relying on timing and combinations of buttons to create a variety of moves. However, these games require fine motor skills and quick reflexes that are beyond the youngest children in our target audience, and would likely frustrate older adults as well.

On the other hand, if we made the controls *too simple*, we risked losing any training value. If players simply pushed a button to scrub the right thumb, we would rob them of any participation in posing and scrubbing the hands, and likely weaken the connection between action *in the game* with that *at the sink*.

After several rounds of playtesting, we moved away from a cluttered user interface that had 7 buttons (plus a left/right setting), to a simper, 3 x 3 grid, shown below in Figure 7.

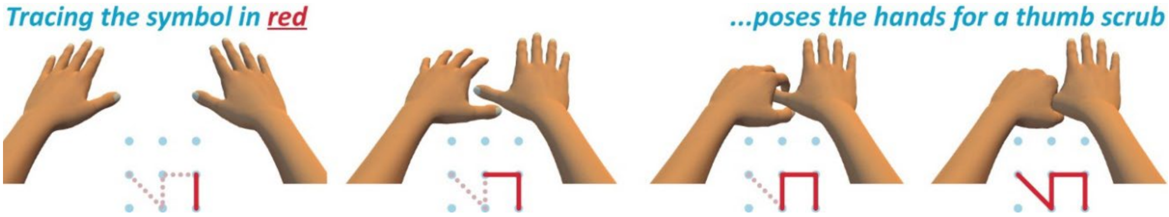


Figure 7: Players pose the hands by drawing a shape that connects dots on a 3 x 3 grid. Each shape is unique, and where possible, suggests the pose itself. In this example, the right thumb scrub shape resembles a hand with a thumb sticking out

This user interface is familiar to Android smartphone users, who use a similar method for unlocking their phones. The interface is compact, giving room to display the hands. An optional hint book helps beginners learn these symbols. When we take the hint book away later in the game, this same interface can be used *for testing:* experienced players can use this interface to demonstrate total recall of every WHO scrub step without prompts.

3.3 Practical Endpoint: Target Behaviour Change in the Real World

Video of handwashing at the sink was recorded before- and after-training for players and scored against a checklist of WHO scrub steps. The results reported elsewhere (Vukanovic-Criley 2025) showed the number of scrub steps performed increased dramatically, from a mean of 5.50 steps to 9.57 steps (t-test, two tails, p = 0.00094).

The videos themselves were a powerful testimony of the effectiveness of this training. Before software training, children who plainly wanted to wash hands well were unable to perform WHO scrub steps they had never learned. These steps, like the thumb scrub shown above in Figures 6 and 7, are distinct, and obvious when done properly. After software training, the players performed these new scrub steps unambiguously.

3.4 Interactive and Responsive: Virtual UV Inspection for Critical Visual Feedback on Handwashing

A second learning game feature we discovered through playtesting. Using fluorescent dye and UV illumination is a practical approach to assessing proficiency at the sink (Deochand 2019, Lee 2014). Glo Germ is a non-toxic hand lotion containing a suspension of fluorescent particles that glow brightly under ultraviolet light, but are otherwise invisible in natural light. Participants apply the lotion and rub their hands until the dye was invisible. Using a UV light box, their hands are photographed with Glo Germ applied, both before washing and after, to highlight areas that were missed by incomplete washing.

To help illustrate how Glo Germ is used, we created a virtual ultraviolet mode in the learning game. Players could wash their virtual hands, then turn on UV illumination to check for any areas of the hands they missed. From the first time we introduced virtual UV inspection to play testers, it proved extremely popular. Players were teaching us how to make the game more engaging. Therefore, we made UV inspection more integral to the gameplay loop. We also made UV more valuable by limiting a player's ability to use it.

Figure 8: UV inspection in the game compared to real life. The first two panels show hands illuminated in natural light, and the same hands under ultraviolet (UV) illumination. UV light reveals fluorescent Glo Germ dye that has not been washed from the fingers and thumbs. Virtual UV inspection: The next two panels show animated hands under natural and UV illumination, depicting white spots where handwashing is incomplete

Gameplay data recorded time on task, time on each step, and order of steps selected. Rounds of playtesting showed the following trends: increased playing time, with more scrub steps performed. The increased playing time indicates higher player engagement. The increase in scrub steps per game indicates that players are *increasing* their *use* of the *virtual UV inspect mode* to check their progress, and then returning to address uncleaned areas, until the job is finished. Maximum scrub steps decreased in August as students became more proficient in use of virtual UV inspection, which revealed when scrubbing was sufficient.

Table 2: Gameplay data from 3 rounds of playtesting

Month	mean playing time (minutes)	mean scrub steps	min scrub steps	max scrub steps
May	7.5	35.8	8	104
July	11.3	48.3	31	127
August	12.8	52.4	34	72

3.5 When to Wash: Immersive Experiential Learning on Disease Transmission

Players learned to wash their hands by witnessing the consequences of *not* washing in the school simulator shown below in Figure 9. The simulator, called Contagion mode, gives players a bird's eye view of classrooms, hallways, bathrooms, cafeterias, and playgrounds. Every time a student in the simulator sneezes, a cone of contamination sprays in the direction he or she was facing. In this simulation, students in this zone of contamination should wash their hands, as well as the student who sneezed. Players can prompt a student in the simulation to visit the sink, to wash his or her hands. This simple game loop delivers powerful learning: other events like a visit to the lunchtime cafeteria, or using the restroom, are layered into the game as the simulation progresses. If a student in the simulation skips handwashing, there is a strong likelihood they will become infected. As the days progress through the simulation, unwashed students can spread germs, develop illness, and become absent from school. If too many students are absent, the school shuts down.

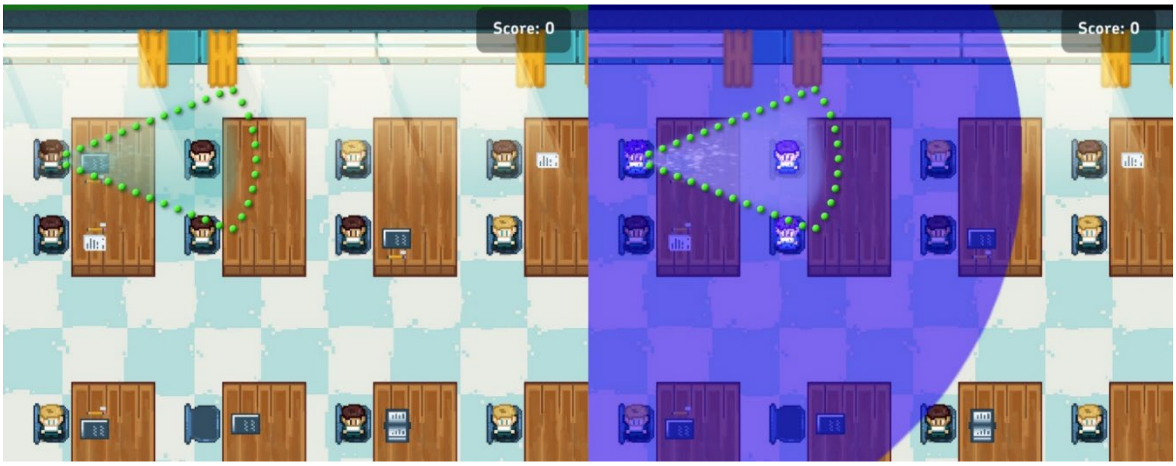


Figure 9: The panel on the left shows a detail from Contagion mode, the simulated classroom in natural light. A child has just sneezed, creating a cone of contamination highlighted with the dotted lines.

The panel on the right shows the same scene with ultraviolet (UV) inspection turned on. In both views, a student has been contaminated

During playtesting, players intuitively clicked on students and discovered that this would prompt them to wash their hands. Without telling them anything about how to play, they quickly discovered the two means of transmission in the first round of the game: respiratory and fecal-oral transmission. Since this initial playtesting, we have added several other viruses and bacteria to the game, each with different profiles of transmission, probability of contracting illness, and speed of development.

3.6 Consistent Practice: Replay Value for Repeated Exposure to Hand Hygiene Training

We developed an achievement system in the learning game that provides the player with short-term, medium-term, and long-term goals. This system invites exploration of the separate modes of the game from training to contagion simulation. It rewards repeated play over several days. And it reveals important facts about hand hygiene, specific pathogens responsible for disease spread, and careers in infectious disease and public health that help prevent outbreaks. Evaluation of the trainer and the achievement system for long-term learning gains is underway.

4. Discussion

Infectious diseases will always be with us. Wherever humans and animals congregate, there is ample opportunity to transmit and amplify viruses, bacteria, and other pathogens. This problem has vexed leaders in cities and commanders of armies since ancient times.

The era of modern public health began in the 19th Century, improving urban life immensely. Pioneers include the Hungarian obstetrician Ignaz Semmelweis, who practically eliminated deaths from post-partum infection in the largest hospital in Vienna by means of careful handwashing—decades before the bacteria responsible for these deadly infections were discovered. In Germany, France, and England, Robert Koch, Louis Pasteur, and John Snow helped usher in the germ theory of disease, microbiology, and the science of epidemiology. These scientific advances have saved more lives than any medicine, surgical procedure, or medical device. To this day, our communities have benefited from systems that deliver clean drinking water, sanitary sewer systems, and countless other public health measures that have been as successful as they are *invisible* (Paiva, 2016, Pedraza 2017).

Yet public health has become a victim of its own success: because it is ubiquitous and invisible, it has also become *mundane*—and, tragically, *misunderstood*—by the very people it hopes to serve. The most recent pandemic exposed and accelerated the erosion of trust between the public and public health officials. Some of this erosion can be attributed to increasing distrust in all institutions, public and private. But this larger social trend does not excuse how poorly prepared our leaders and institutions were, how incoherent the messaging was, and how much public goodwill, which was in abundance early on, was squandered.

Handwashing is both cheap and effective protection against a host of transmissible diseases. Through proper training, healthcare-level proficiency in hand hygiene is possible for both children and adults. The missing component has been scalable, standardized training, to a high level, that not only transfers effective technique, but also fosters healthy habit formation. The design of the interactive trainer, reported here, has features that can be applied to other learning domains: high-fidelity simulation not only reduces the cognitive load, but also allows training to a very high standard. Close connection of the learning game to the desired behaviour, and evaluation of that behaviour in real life, has the greatest chance of improving health outcomes. Experiential learning invites players to discover for themselves when handwashing is indicated, and the consequences of skipping it. Finally, awareness of how behaviours form, and how they can be reinforced through repeated gameplay, can deliver lifelong benefits to health.

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Conflict of Interest: The authors are or were employees of Indelible Learning, which developed and tested the learning game.

Declaration of generative AI and AI-assisted technologies in the writing process: None were used.

References

Ajzen, I. (1991). The theory of planned behavior. *Org. behavior and human decision processes*, *50*(2), 179-211.

Al-Tawfiq, J. A., & Pittet, D. (2013). Improving hand hygiene compliance in healthcare settings using behavior change theories: reflections. *Teaching and learning in medicine*, *25*(4), 374-382.

Bubble Beats Trainer (2025). Indelible Learning app for hand hygiene. https://apps.apple.com/us/app/bubble-beats-trainer/id6447053353

Baranowski, T., Blumberg, F., Buday, R., et al. (2016). Games for health for children—Current status and needed research. *Games for health journal*, 5(1), 1-12.

Baranowski, T., Cullen, K.W., Nicklas, T., et al. (2003) Are current health behavioral change models helpful in guiding prevention of weight gain efforts? *Obesity Research*. 2003 Oct;11(S10):23S-43S.

Deochand, N., Hughes, H. C., & Fuqua, R. W. (2019). Evaluating visual feedback on the handwashing behavior of students with emotional and developmental disabilities. *Behavior Analysis: Research and Practice*, 19(3), 232–240.

Eiamsitrakoon, T., Apisarnthanarak, A., Nuallaong, W., et al (2013). Hand hygiene behavior: translating behavioral research into infection control practice. *Infection Control & Hosp Epidem*, *34*(11), 1137-1145.

Godin, G., & Kok, G. (1996). The theory of planned behavior: a review of its applications to health-related behaviors. *American journal of health promotion*, *11*(2), 87-98.

Hegarty, M. (2011). The cognitive science of visual-spatial displays: Implications for design. *Topics in cognitive science*, *3*(3), 446-474.

Jess, R. L., & Dozier, C. L. (2020). Increasing handwashing in young children: A brief review. *Journal of Applied Behavior Analysis*, 53(3), 1219-1224.

Johns Hopkins Medicine [JHU] (2019, March 26) Hand-washing Steps Using the WHO Technique [Video] YouTube. https://www.youtube.com/watch?v=IisgnbMfKv

Kang, Y. S., & Chang, Y. J. (2019). Using a motion-controlled game to teach four elementary school children with intellectual disabilities to improve hand hygiene. *Journal of Applied Research in Intellectual Disabilities*, *32*(4), 942-951.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and higher education*, *8*(1), 13-24.

Lee, R. L. T., Leung, C., Chen, H., et al. (2022). Five-step hand hygiene programme for students with mild intellectual disability: Abridged secondary publication. *Hong Kong Medical Journal*, *3*(3), 41-42.

Lee, R. L., Leung, C., Tong, et al. (2015). Comparative efficacy of a simplified handwashing program for improvement in hand hygiene and reduction of school absenteeism among children with intellectual disability. *American journal of infection control*, 43(9), 907-912.

MacKinnon, D. P. (2011). Integrating mediators and moderators in research design. *Research on Social Work Practice*, 21(6), 675-681.

Ishikawa, T., & Newcombe, N. S. (2021). Why spatial is special in education, learning, and everyday activities. *Cognitive research: Principles and implications*, *6*(1), 20.

Noar S.M., Zimmerman R.S. (2005) Health Behavior Theory and cumulative knowledge regarding health behaviors: are we moving in the right direction? *Health Education Research*. 2005; 20(3):275-290.

Paiva, J., Morais, C., Costa, L., et al. (2016). The shift from "e-learning" to "learning": Invisible technology and the dropping of the "e". *British Journal of Educational Technology*, *47*(2), 226-238.

Pedraza, F. (2017). Technology is best when invisible. Medium. https://medium.com/invisible/technology-is-best-when-invisible-2b72e31c6e4a

Prochaska, J.O., Velicer, W.F. (1997). The transtheoretical model of health behavior change. *Am J of Health Promotion*. 1997 Sep;12(1):38-48.

Schwarzer, R. (2008). Modeling health behavior change: How to predict and modify the adoption and maintenance of health behaviors. *Applied psychology*, 57(1), 1-29.

Sharmin, N., Chow, A. K., & King, S. (2023). Effect of teaching tools in spatial understanding in health science education: A systematic review. *Canadian Medical Education Journal*, 14(4), 70-88.

Sheeran, P., Klein, W. M., & Rothman, A. J. (2017). Health behavior change: Moving from observation to intervention. *Annual review of psychology*, *68*(1), 573-600.

Sponge. (2016). Handwashing Game. Southern Health NHS Foundation Trust. Archived from the original at https://web.archive.org/web/20200929203850/https://wearesponge.com/insights/2020/03/handwashing-game

Srigley, J. A., Corace, K., Hargadon, D. P., et al. (2015). Applying psychological frameworks of behaviour change to improve healthcare worker hand hygiene: a systematic review. *J of Hospital Infection*, *91*(3), 202-210.

SureWash: A Kid's Journey. (2024). Surewash. https://apps.apple.com/us/app/surewash-a-kids-journey/id1295117034

SureWash Hand Hygiene. (2020). Surewash. https://apps.apple.com/us/app/surewash-hand-hygiene/id6736437299

Trunnell, E. P., & White Jr, G. L. (2005). Using behavior change theories to enhance hand hygiene behavior. *Education for health*, *18*(1), 80-84.

Vukanovic-Criley, J., Batra, J., Ing, D., et al. (2025). Improving Hand Hygiene with Interactive Training: Evaluation. *Proceedings of the 2025 Connected Learning Summit*. Carnegie Mellon University ETC Press.

World Health Organization [WHO]. (2009) WHO Guidelines on Hand Hygiene in Health Care. https://www.who.int/publications/i/item/WHO-IER-PSP-2009.07

Younie, S., Mitchell, C., Bisson, M. J., et al. (2020). Improving young children's handwashing behaviour and understanding of germs: The impact of A Germ's Journey educational resources in schools and public spaces. *PLoS One*, *15*(11), e0242134.