Teaching best practice in hand hygiene: student use and performance with a gamified gesture recognition system

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Abstract
The use of an automated gesture recognition system to teach the commonly adopted, seven-stage hand hygiene technique to veterinary undergraduate students was evaluated. The system features moderate gamification, intended to motivate the student to use the machine repeatedly. The system records each handwash stage, and those found to be difficult are identified and reported back. The gamification element alone was not sufficient to encourage repeated use of the machine, with only 13.6 per cent of 611 eligible students interacting with the machine on one or more occasion. Overall engagement remained low (mean sessions per user: 3.5, ±0.60 confidence interval), even following recruitment of infection control ambassadors who were given a specific remit to encourage engagement with the system. Compliance monitoring was introduced to explore how students used the system. Hand hygiene performance did not improve with repeated use. There was evidence that the stages—fingers interlaced, rotation of the thumb, rotation of the fingertips and rotation of the wrists—were more challenging for students to master (p=0.0197 to p<0.0001) than the back of the hand and of the fingers. Veterinary schools wishing to use such a system should consider adopting approaches that encourage peer buy-in, and highlight the ability to practise difficult stages of the technique.

Introduction
Higher education has a long association with technological innovation, utilising many novel instructional tools.1 Within veterinary education specifically, there has been a particular increase in game-based learning (GBL), exemplified by the increasing interest in simulation tools to teach practical skills in a safe environment.2 GBL is the practice of incorporating elements from games into learning, particularly concepts like competition and leader boards. It is thought to promote self-reliance and autonomy, increase learner motivation, and provide opportunities for authentic and experiential learning.3 ‘Gamification’ is the use of video-game elements in novel contexts, and in GBL it is used primarily to increase learner engagement with a teaching activity.4 Any logical task can be gamified by recognising when a user has progressed through a series of stages towards an end goal, and providing a positive reward at each progression.5 Landers5 proposed that game characteristics act on behaviours or learner attitudes as a mediator to the instructional content, to influence the attainment of learning outcomes, highlighting that gamification cannot make up for a lack of defined learning outcomes. This is echoed by a repeating theme in the literature that while faculty are often keen to incorporate technology into teaching, the exact mechanisms through which the technology improves learning attainment are not always considered.16 There is also a social component to gamification, often through the competitive element of leader boards, and the public aspect of having performance recorded can be a great motivator for even potentially unpleasant tasks such as fitness regimens.7 GBL is often deemed highly attractive due to its ‘fun’ perception, and has generated funding interest in turn8; however, it remains important to continue to evaluate aspects of GBL in situ during veterinary education programmes.
Compliance with hand hygiene protocols is a challenging issue for all veterinary and healthcare workers. Effective hand hygiene practices have been shown to reduce the risk of healthcare-associated infections and help prevent the spread of antimicrobial resistance, with multimodal training strategies proving the most effective in promoting compliance. Hand hygiene compliance is affected by a number of factors, including awareness of hygiene importance, availability of hand hygiene resources such as alcohol rubs present at patient contact sites, adherence to hand washing protocols and the healthcare worker’s role.10–15

The World Health Organization (WHO) standardised a six-stage procedure for effective hand hygiene,16 17 which is commonly modified by adding an additional stage after stage 6, in which each wrist is cleaned in turn by rotational rubbing, to give a seven-stage protocol. Skills acquisition is highly related to procedural memory,18 with frequently repeated actions stabilising interlocked actions in organisational routines.19 Given hand hygiene compliance is affected by awareness and adherence to protocols, regular practice of the hand hygiene protocol is considered an important aspect of improving general hygiene practices. Engaging learners in repetitive practice, for example, through simulations, can be an effective learning strategy.20

The SureWash system (Glanta, Dublin, Ireland) uses gesture recognition technology to monitor each of the seven stages of the modified hand hygiene protocol and evaluate whether the user’s movements fall within acceptable bounds. In validation studies, the system’s recognition of hand movements showed substantial agreement with a human observer.21 Alongside the gesture recognition, the SureWash system provides a score for the user, which is a gamification element that is thought to incentivise repeated practice as users try to better their previous score. SureWash units have previously been used to encourage uptake of training in hospitals show that compliance is variable.

Students currently receive hand hygiene training in a practical class in year 1, then assessments in years 1 and 5, have access to hand rub and hand washing videos, and can request any additional training via the clinical skills team at any time, but observations in the hospitals show that compliance is variable.

### Materials and methods

#### Cohort selection

The Royal (Dick) School of Veterinary Studies (R(D) SVS) is based in Scotland, UK, and runs a five-year undergraduate veterinary degree programme (UG-P). A four-year, graduate entry programme (GE-P) runs alongside the standard UG-P, for postgraduate students who have previously obtained a relevant degree. The GE-P comprises an extended first year that combines elements from the first and second years of the UG-P. After completing their first year, students on the GE-P join students completing year 2 of the UG-P, such that both programmes run together for the final three years of each programme.

Each teaching year group was considered as a separate cohort, such that five individual cohorts were available on campus for the duration of the study: GE-P year 1; UG-P year 1 and year 2; and year 3 and year 4 (year 3 and year 4 each consists of the combined GE-P and UG-P years).

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#### The SureWash system

The SureWash system is presented as a portable unit, comprising an overhead camera pointed at the user’s hands with an LCD (liquid crystal display) screen mounted at eye level (figure 1). The system offers two modes of instruction, a training mode and an ‘assessment’ mode.24 The assessment mode provides the scores for each stage of the handwash (table 1) and in typical day-to-day use is the only mode accessed by a user. The training mode is optional for all users. The user is prompted to roll up their sleeves if required, and a photograph of the user’s hands and wrists is captured at the start of each attempt (figure 2). The first part of the training mode presents information about each of the hand hygiene stages, explaining why the stage is important, and presents a short video clip demonstrating the correct performance of the stage. The user is offered the opportunity to perform the step and the system provides feedback. An incorrect gesture prompts the system to provide more information, outlining common mistakes. A correct gesture allows access to the next stage.

The assessment mode requires the user to perform all seven stages correctly in sequence. Following the assessment, the user is given a score, feedback on stages performed correctly, and the
Figure 1  Carrying out hand hygiene training with the SureWash system. The user’s hands are imaged by an overhead camera and displayed on the left of the screen in near-real time. The correct performance of the hand hygiene stage is shown on the upper right with all the hand hygiene steps in a sequential diagrammatic format underneath this.

| Hand hygiene stage | Description |
|--------------------|-------------|
| Prewash            | Apply product to cupped palm. |
| 1                  | Rub hands palm to palm. |
| 2                  | Right palm over the left dorsum with interlaced fingers and vice versa. |
| 3                  | Palm to palm with fingers interlocked. |
| 4                  | Back of fingers to opposing palms with fingers interlocked. |
| 5                  | Rotational rubbing of the left thumb clasped in the right palm and vice versa. |
| 6                  | Rotational rubbing, backwards and forward with clasped fingers of the right hand in the left palm and vice versa. |
| 7 (not within the WHO protocols) | Rotational rubbing of the wrists. |
| Postwash           | Once dry, hands are considered safe. |

WHO, World Health Organization.

opportunity to repeat the assessment or enter training mode again.

A pass for each stage is awarded by the SureWash system when the user has demonstrated that the stage has been effectively completed. If the user does not perform the required hand movements effectively or with the required number of repeats, the step is failed. Users can opt to move on should they become stuck at any stage. Within the assessment mode, there is a series of levels. Once all handwash stages have been completed, users are allowed to progress up to the next level in the assessment mode. The first level includes a video clip that prompts the hand motion required for each stage, and as the user progresses up the levels, visual cues are removed until the user can carry out all stages correctly from memory without having to refer to guidance.

At the completion of each stage, immediate feedback is given as to whether the user has passed or failed overall. Information is given on which stages the user found difficult (as evidenced by the time taken to complete each stage), which stages were failed and the overall time to complete the process, and the user is given the choice to retry the level, enter training mode or if they have passed to move up a level.

Distinguishing real attempts

Initial evaluation of the data and observation of user behaviour with the machine showed a rare behaviour which was termed a ‘fake fail’. In the assessment mode, if early on the handwash stage process, a user might exit the mode when the machine indicated they failed a handwash stage. They would immediately restart the level to repeat the failed stage and have a better score. The SureWash system records an aborted attempt (ie, where the user exits the mode after an early stage fail) as a completed session where all subsequent stages have been attempted and failed, even when the user does not attempt the subsequent stages. As sessions would not be observed, the authors needed to establish a criteria which could distinguish these ‘fake fails’ where the final stages had not been performed from a real attempt where multiple handwash stages had been attempted and failed. The criteria adopted was that any attempt where the user did not engage with more than three of the seven handwash stages during an assessment mode session was excluded. This excluded six attempts from subsequent analysis. Of the sessions which were retained in the data set, only five attempts (from unique students) scored 0 per cent on the final stage, and these attempts had all participated in the previous six stages, and so were retained as a true example of the student having a technique issue with the seventh stage.

Stage 1: self-motivated use

To introduce the machine to the school and explore initial usage patterns, a single SureWash station was positioned in a high-traffic location of the R(D)SVS teaching building seven days before a UG-P year 1 summative examination in hand hygiene. Information was emailed to each year 1 student (n=128) inviting them to use the machine to help prepare for the upcoming examination. Additionally, the SureWash machine was introduced to the year during an associated lecture on infection control and biosecurity. Students were able to log in to the machine via a prepopulated list of user names or to access the machine via an anonymous ‘visitor’ account.
Stage 2: ambassador-motivated use

In the second part of the study, in response to the patterns of behaviour observed in stage 1, the social aspect of gamification was leveraged, to encourage a higher uptake. A swipe card was installed onto the SureWash to log and record user interaction and progress. One volunteer was recruited from each of the five year cohorts to act as an infection control ambassador (ICA). Each ICA was tasked with encouraging interaction with the SureWash system and to improve understanding of hand hygiene methods. To motivate each individual ICA was provided with a project T-shirt and a chance to win an iPad if their year showed the greatest proportional engagement with the SureWash machine.

One-to-one training on the machine’s use was given to each ICA. They were each encouraged to get as many students as possible from their year cohort to engage with the system and were able to book private-use times to allow drop-in sessions to be run.

Statistical analysis

Performance was compared across year cohorts and attempts.

All analyses were conducted in R Studio Version 0.99.903 (RStudio: Integrated Development for R, RStudio, Boston, Massachusetts; http://www.rstudio.com/) using R Version 3.4.2, Short Summer (Copyright 2018, The R Foundation for Statistical Computing). To explore the differences in user performance across the different stages of the SureWash assessment, a multilevel model was adopted to take into account (1) that users could have as many sessions with the SureWash machine as they wanted and (2) that the year groups were uneven in numbers. The response variable was the SureWash score as a measure of the user’s hand hygiene performance. As data were only collected at the aggregate level, for example, each user only received one aggregated score regardless of the number of attempts, it was not possible to test whether different stages improved with time or whether the order of stages passed affected the likelihood to try again. User identification (ID) was treated as a random term, as users were considered sampled from the larger veterinary student population, following the Grafen and Hails’ interpretation of random effects.25 Due to the limited sample size, the authors were only able to model random intercepts, not random slopes. Therefore, the model assumed that each student may have a different starting point in terms of their hand hygiene knowledge but that the fixed terms in the model would have consistent effects on each individual (ie, the SureWash system is calculated to have the same effect on each score and does not mathematically calculate the strength of the effect for each individual user). The handwash stage, number of sessions and student year group were all considered fixed effects. That is to say the model assumed that the authors were sampling from a larger veterinary student population, and were interested in how handwash stage, year group and the number of times a student accessed the SureWash machine could affect the overall response of user performance, as measured by SureWash score. Several models were created, including all combinations of the fixed and random effects. The best model was selected through formal comparison of the deviances via an analysis of variance, which concurred with both Akaike’s information criterion and Bayes information criterion comparisons across all models.25

Results

Stage 1: self-motivated engagement

Many users opted to use the visitor access (n=60) rather than log in to the machine with their own unique identifier, which meant it was not possible to know if these interactions were from year 1 students, staff or visitors; therefore, in stage 1, the authors can only talk about attempts and not per user.

Of those who elected to swipe in during the seven-day access period from the UG-P year 1 cohort of 128 students, the SureWash machine was used by 29 unique students (22.7 per cent of the cohort) a total of 98 times. Of these attempts, 62 attempts featured a failure (defined as a failure to pass all hand hygiene stages in the level attempted) and 36 attempts passed all hand hygiene stages. These 36 passes came from only six identified users.

Stage 2: ambassador-motivated engagement

In the second stage, visitor access was removed to obtain a clearer oversight of how year groups used the machine and to facilitate the ICA competitive aspect of the intervention. Over the 27-day access period, 83 students from a total number of 611 across all five cohorts used the machine (table 2). The mean duration

Figure 2 At the start of the attempt, a photograph of the hands and wrists is captured. This allows an observer to verify compliance with the ‘bare below the elbow’ policy, which includes removing wrist and (most) hand jewellery, false nails and nail polish. Here one user (left) is seen to be wearing a watch and a wristband, while the remaining users (central and right) are seen wearing acceptable plain wedding bands.
of the first session was 105 seconds (±5.0, 95 per cent confidence interval (CI)). Across all 83 participants, the mean number of attempts per user was 3.5 (±0.60 CI). The maximum number of attempts by any one user was 11.

The model with the best fit of the data treated wash stage as a fixed effect and user ID as a random effect, with year cohort and the number of attempts the user made proving non-significant when user ID was considered. When considering student ID as a random effect, that is, each student may have a different grasp of hand hygiene, the student’s year group and the number of attempts they undertook become non-significant. Therefore there was no evidence to support the first hypothesis that an increased number of attempts with the machine would improve hand hygiene performance, or the second hypothesis that year cohorts with a higher number of attempts would attain higher scores.

Across the seven distinct stages of the hand washing process, however, significant differences in score were noted, with the three stages featuring rotation proving more difficult to master (table 3). This can be seen in the generally poorer scores of the rotation stages across all students (figure 3). This provides evidence to support the third hypothesis, that students find some stages of the hand hygiene protocol more challenging to master than others.

Discussion

There are a number of valuable observations from the study which can be incorporated in hand hygiene teaching in practice and school environments. The relatively low uptake of use of the machine suggests that the gamification element alone was insufficient to motivate students to repeatedly access the machine to practise the hand hygiene protocol, even in the face of an imminent summative assessment. In some courses, gamification has been shown to reduce student motivation, satisfaction and empowerment, and so the implementation of gamified learning systems should be done carefully, with thought as to how they can reflect the curriculum. It is possible that, in this case, the motivation of the final score did not provide sufficient incentive for the students to repeatedly access the machine, practise and refine their skills, and ultimately improve their score. Veterinary students are generally considered to be highly competitive and goal-focused, so if such students do not find the gamified system engaging enough it raises the question of what could be done to make the system more motivating.

The second part of the study revealed clear differences in uptake between the year cohorts, which was thought to be associated primarily with the ICAs’ level of engagement. One ambassador (GE-P) took the SureWash machine in to a lecture to increase year group engagement and encouraged students to use it as they left at the end of the lecture. The GE-P year demonstrated the highest engagement both in terms of the absolute number of students who engaged with the machine and the number of attempts each student engaged in. The GE-P year is often anecdotally noted to be a very close community, perhaps in part due to the condensed nature of their first year of study, and it is

| Table 2 | Summary statistics across year group for SureWash sessions (mean±95% confidence interval) |
|---------|------------------------------------------------------------------------------------------|
| Year    | Students in the cohort | Number of users interacting with the system | Mean number of attempts per user | Mean duration of first attempt (seconds) | Mean number of passes per user |
| GE-P year 1 | 52 | 35 | 6.0 (±0.77) | 107.8 (±6.64) | 3.5 (±0.45) |
| UG-P year 1 | 128 | 14 | 1.4 (±0.39) | 101.7 (±7.94) | 0.6 (±0.45) |
| UG-P year 2 | 121 | 9 | 2.2 (±1.49) | 115.3 (±19.56) | 1.2 (±0.54) |
| Year 3 | 164 | 23 | 1.8 (±0.47) | 99.6 (±11.90) | 1.0 (±0.52) |
| Year 4 | 146 | 2 | 1 | 99.0 (±25.48) | 0.5 (±0.98) |
| Total | 611 | 83 | 3.5 (±0.60) | 105.1 (±5.04) | 2.0 (±0.38) |

GE-P, graduate entry programme; UG-P, undergraduate veterinary degree programme.

| Table 3 | Fixed effects for linear mixed-effects model predicting score by SureWash stage, fit by maximum likelihood, with student identification fitted as a random effect |
|---------|------------------------------------------------------------------------------------------|
| Back of hand | 0.03 | ±0.037 | 452 | 0.89 | 0.3747 |
| Fingers interlaced | -0.09 | ±0.037 | 452 | -2.34 | 0.0197 |
| Back of fingers | 0.06 | ±0.037 | 452 | -1.71 | 0.0877 |
| Rotation of thumb | -0.22 | ±0.037 | 452 | -5.88 | <0.0001 |
| Rotation of fingertips | -0.16 | ±0.037 | 452 | -4.39 | <0.0001 |
| Rotation of wrists | -0.12 | ±0.037 | 452 | -3.79 | 0.0008 |

Note that stage 1, palm to palm, is not included as the effect is estimated against this stage.

![Figure 3](image) Mean score (±95% confidence interval) for each stage of the hand hygiene protocol as compared with the initial stage (palm to palm). Significance (*p<0.01, ***p<0.001) in a linear mixed-effect model fit by maximum likelihood, with user identification as a random effect.
possible that this closeness inspired competitiveness either within the cohort or against other year groups. It is well documented that high levels of trust within teams can inspire greater competitiveness with other groups.28

The authors found no systematic effect of year of study or number of attempts on performance of the hand hygiene protocol, even though they may have expected more experienced students to have a better grasp of the hand hygiene protocol given their time in clinical studies. The authors did find evidence that the rotational movements and interlaced finger stages appeared to be more challenging to learn for all students, suggesting that these stages may require more focus when teaching the WHO method of hand hygiene.

From the standpoint of learning design, the lack of a relationship between the number of attempts and performance is unexpected (as demonstrated by the number of attempts proving insignificant in the model). Within study 1, the SureWash system was provided as an additional tool to help prepare for a summative assessment, and yet engagement remained very low. In study 2, the number of attempts did not improve the chances of performing the hand hygiene protocol appropriately, despite the user being given direct and immediate feedback on their performance.

There are a number of limitations to this study. The passive nature may have resulted in a relatively small data set (n=83 students), whereas if students had been required to access the machine at least once there would certainly have been a larger sample of initial measures. However, the SureWash system was intended to be a supplementary study aid that would, through its gamified design, encourage students to repeatedly practise hand washing. At the point of study design, there was no evidence to suggest that students would require extra incentive to interact with the machine, and the steps taken before study 2 to further incentivise students did bring greater engagement. The practice of evidence-based education includes both the critical evaluation of evidence and the establishing of new evidence through interdisciplinary research.29 Some researchers have criticised an overemphasis on ‘what works’ questions as opposed to ‘why does this work’ given the complexity of the confounding factors that affect human behaviour.30 This study focused on exploring ‘what works’, and future work should explore why, as at present there is limited mechanistic exploration of the acquisition of hand hygiene skills.

It may be that the SureWash system is not appealing to students, either because it does not appeal aesthetically or it is not perceived to provide useful feedback. Alternatively, the hand hygiene skill itself may not be perceived as a useful or important skill, which may be borne out by the repeated challenge faced by all medical institutions of achieving compliance with hand hygiene protocols. The authors can only speculate as to these due to the lack of qualitative data, which would have allowed them to answer the ‘why’ questions.30 Future studies may also wish to explore whether it is possible to link these skill acquisition practices with skill assessments, such as objective structured clinical exam (OSCE) performance.

The difference identified in performance across the hand hygiene stages is also an interesting result. As stated previously, achieving compliance with hand hygiene, despite its widely recognised importance, is challenging, and a clear difference in the perceived difficulty at certain stages is a useful information which can be fed into future teaching. The authors also have to consider whether this result is genuine, given that any automated system can be vulnerable to error. The machine may be less able to ‘see’ these steps, and so wrongly denies marks for these sections. However, previous work has shown high agreement between the machine and human observers.30 Further, given the importance of hand hygiene, it may be reasonable to be conservative in establishing whether a stage has been correctly performed.

Ultimately, the gamification elements of this system did not appear to spur learner engagement, although the data gathered by the machine were useful in informing educators about the areas that students found more challenging within the hand hygiene process.

There were a number of key outcomes from this piloting of the SureWash system in veterinary education, which might enable schools to make more use of such automated systems. For gamification to work, the authors found the adoption of the ambassador scheme to be a critical element in encouraging repeated use of the machine. The variation across the year groups concurred with the tutors’ perceptions of the student cohorts’ academic engagement, suggesting that recruitment to such schemes is a strong component of increasing motivation. Traditional interpretation of gamification assumes that the gamified elements, for example, performance scores, will be enough to increase motivation. The results of this study better align with more recent opinions on gamification which suggest that low-pressure environments in which learners can fail might be a more useful component of ‘playful’ educational interventions.31 Thus, gamified gesture recognition systems need to be incorporated into school-wide awareness campaigns for effective infection control, and not considered a single intervention to improve hand hygiene compliance. As the rental or purchase of such gesture recognition systems is a significant expense, the authors would also encourage a swipe log-in system from day 1 to make better use of the performance data. This might be particularly relevant, for example, in the run-up to objective structured clinical examinations, enabling students to practise the more difficult steps with immediate feedback.
Summary
Although the potential for gesture recognition technology to become a useful tool in promoting and encouraging veterinary undergraduates to engage with and develop effective hand hygiene skills and practices is exciting, its incorporation into the curriculum requires careful consideration as students may not be motivated to interact spontaneously with the technology, given the level to which the gamified aspects have been developed. The value of the system improved when paired with a peer-based, ambassador-led scheme which encouraged playful learning through friendly competition. The system also identified which aspects of a hand hygiene protocol were most challenging for students to learn, and how participation varied according to student engagement from different year groups.

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Competing interests
None declared.

Ethics approval
Ethical review was performed and approval granted by the Human Ethics Review Committee of the host institution (reference: HERC_82_17). Students were made aware of the trial during lectures, that using the machine would support their cohort ambassador and that data from the machine would be used in the ensuing evaluation. If students did not wish to join the trial, they could opt not to use the machine.

Data availability statement
Data are available upon request.

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