ORIGINAL ARTICLE

The Value of E-Learning for the Prevention of Healthcare-Associated Infections

Sonia O. Labeau, PhD;[1] Jordi Rello, PhD;[2] George Dimopoulos, PhD;[3] Jeffrey Lipman, PhD;[4] Aklime Sarikaya, PhD;[5] Candan Oztürk, PhD;[5] Dominique M. Vandijck, PhD;[6] Dirk Vogelaers, PhD;[7] Koenraad Vandewoude, PhD;[7] Stijn I. Blot, PhD[4,7] for the EVIDENCE Research Team

BACKGROUND. Healthcare workers (HCWs) lack familiarity with evidence-based guidelines for the prevention of healthcare-associated infections (HAIs). There is good evidence that effective educational interventions help to facilitate guideline implementation, so we investigated whether e-learning could enhance HCW knowledge of HAI prevention guidelines.

METHODS. We developed an electronic course (e-course) and tested its usability and content validity. An international sample of voluntary learners submitted to a pretest (T0) that determined their baseline knowledge of guidelines, and they subsequently studied the e-course. Immediately after studying the course, posttest 1 (T1) assessed the immediate learning effect. After 3 months, during which participants had no access to the course, a second posttest (T2) evaluated the residual learning effect.

RESULTS. A total of 3,587 HCWs representing 79 nationalities enrolled: 2,590 HCWs (72%) completed T0; 1,410 HCWs (39%) completed T1; and 1,011 HCWs (28%) completed T2. The median study time was 193 minutes (interquartile range [IQR], 96–306 minutes).

The median scores were 52% (IQR, 44%–62%) for T0, 80% (IQR, 68%–88%) for T1, and 74% (IQR, 64%–84%) for T2. The immediate learning effect (T0 vs T1) was +24% (IQR, 12%–34%; $P < .001$), and a residual effect (T0 vs T2) of +18% (IQR 8–28) remained ($P < .001$). A 200-minute study time was associated with a maximum immediate learning effect (28%). A study time >300 minutes yielded the greatest residual effect (24%).

CONCLUSIONS. Moderate time invested in e-learning yielded significant immediate and residual learning effects. Decision makers could consider promoting e-learning as a supporting tool in HAI prevention.

Infect Control Hosp Epidemiol 2016;37:1052–1059

Healthcare-associated infections (HAIs) affect 5% to 10% of patients in acute-care hospitals and up to 33% of those admitted to the intensive care unit (ICU).[1] The Big Four infection types account for >80% of all HAIs: (1) ventilator-associated pneumonia (VAP), (2) central line-associated bloodstream infection (CLABSI), (3) surgical site infection (SSI) and (4) catheter-related urinary tract infection (CAUTI).[2] Their impacts in terms of excess morbidity and expenditures have led to a transition from accepting HAIs as an inevitable outcome of hospital admission to a goal of zero tolerance.[1,3]

Compliance with current evidence-based guidelines (EBGs) could prevent up to 70% of cases of CLABSI and CAUTI as well as 55% of cases of VAP and SSI.[4–6] Unfortunately, adherence rates among HCWs are often low,[7,8] as are their levels of guideline knowledge.[9–12] The results of various multiple-choice knowledge tests (MCTs) completed by >3,000 European intensive care unit (ICU) nurses never exceeded the conventional 50% threshold to pass a test.[10,12]

There is good evidence that effective educational interventions help to facilitate guideline implementation.[13] E-learning, a method that integrates information technology and the learning process using material delivered through the Internet,[14] has been acknowledged as a valuable educational tool.[15]

In this paper, we report the development of an e-course that bundles the essentials of evidence-based HAI prevention and its contribution to the acquisition and retention of knowledge regarding evidence-based strategies for infection prevention among an international cohort of HCWs.

Affiliations: 1. Faculty of Education, Health and Social Work, University College Ghent, Ghent, Belgium; Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium; 2. Critical Care Department, Vall d'Hebron University Hospital, CIBERES, Universitat Autonoma de Barcelona, Barcelona, Spain; 3. Department of Critical Care, Medical School, University of Athens, ATTIKON University Hospital, Athens, Greece; 4. Burns Trauma and Critical Care Research Centre, The University of Queensland, Brisbane, Australia; 5. Faculty of Health Sciences, Department of Nursing, Istanbul Sabahattin Zaim University, Istanbul, Turkey; 6. Department of Patient Safety and Health Economics, Hasselt University, Diepenbeek, Belgium; Department of Public Health, Ghent University, Ghent, Belgium; 7. Department of Internal Medicine, Ghent University, Ghent, Belgium.

Received December 7, 2015; accepted April 15, 2016; electronically published May 13, 2016

 0899-823X/2016/3709-0007. DOI: 10.1017/ice.2016.107

METHODS

Course Development

The e-course was developed in the Dutch language using open-source software eXe, release 1.04.0.3532 (http://exelearning.org). The layout was embellished by a web designer. Forward and backward translations of the course were effectuated in English, Portuguese, Spanish, and Turkish languages. To optimize accessibility, only a computer with Internet access and a web browser were needed to study the course; no plug-ins, additional software, or downloads were required.

The validity of the course content was assessed and approved by an international team of experts in infection prevention (S.I.B., D.M.V., J.L., G.D., J.R.). A sample of 50 potential users acknowledged the face validity of the course and its usability according to the Software Usability Measurement Inventory (SUMI), a proven method of measuring software quality from the end user's point of view.[16] In addition to a general score, SUMI measures 5 subdimensions of software usability: (1) the affect subscale quantifies the user's emotional reaction to the software; (2) efficiency reflects the software's transparency; (3) helpfulness measures the degree to which the software is self-explanatory and has "help" facilities; (4) control reveals the extent to which users feel in control of the software; and finally, (5) learnability indicates the speed and ease of mastering the system.

Course Contents

The course comprised 7 chapters. The overall focus of the course was evidence-based practice, and the first chapter was dedicated to this concept. The second chapter introduced the problem of HAIs and emphasized the importance of prevention. Hand hygiene, which is key to preventing infection, was discussed in the third chapter. Chapters 4–7 were focused on each of the Big Four, respectively. Each chapter could be studied separately. Different types of exercises with immediate feedback, such as case studies, cloze exercises, and MCTs were integrated to allow self-evaluation during the learning process.

Recruitment of the Sample

An international sample of voluntary learners was recruited through repeated international promotional campaigns: e-flyers were mailed to professional organizations and members of existing networks; flyers were distributed at an (inter)national congresses; and e-mails were sent to all members of the Flemish Society for Intensive Care Nurses (VVIZV) and the European Society for Intensive Care Medicine (ESICM), which endorsed the study.

As an incentive, a certificate of participation issued by the ESICM was acquired upon completion of the entire study path.

Inclusion and Exclusion Criteria

The course was originally designed for HCWs dealing with critically ill patients, but with the exception of VAP prevention, all topics included were valid for non-ICU clinicians as well. Because numerous healthcare professionals working outside the ICU environment also explicitly showed interest in the course, involvement in inpatient care was set as the only requirement for study participation; no exclusion criteria were defined. As such, enrollment was open to all HCWs and students.

Enrollment

A study website (www.evidenceproject.org) was created to provide information about the study design, to allow participants to grant informed consent, enroll, and access the course. The site also provided information on the background, aims, and design of the study. The website was open for registration from October 30, 2010, until December 31, 2011. All transactions on the study site were closed on July 15, 2012.

Study Path

An automated e-mail system guided registered participants through the study path (Fig. 1): (1) An initial e-mail invited participants to log in to the study site and complete a 50-item MCT. (2) After electronic submission of this pretest (T0; measured prior knowledge), participants were automatically granted access to the course for a maximal period of 8 weeks, but students who felt that mastering the course earlier could end the study period as soon as they wanted. After 6 weeks, an automated e-mail alert about the imminent end of the study period was sent. (3) Immediately after the study period, an automated e-mail invited the participants to complete a second 50-item MCT (posttest1; T1; measured immediate learning effect). These questions were identical to those of T0 but were ranked differently.[17] (d) At 12 weeks after submitting T1 and without further access to the course, participants were invited by automated e-mail to complete a third and final 50-item MCT (T2; measured residual learning effects). Again, these questions were identical to those of T0 and T1 but, again, were ranked differently.[17]

MCT

The MCT consisted of 1 correct answer, 2 distractors, and the answering option "I do not know" to restrain participants from guessing (see Supplementary Material). The MCT underwent face and expert content validation, and its reliability was assessed by means of item analysis using methods similar to those described elsewhere.[11,18,19] Face and content validity were achieved for all items and the results of the item analysis supported the questionnaire's reliability. Test scores were calculated as follows: correct answer = 1 point; wrong answer or "I do not know" = 0 points. There was no correction for guessing. Correct answers and feedback on test scores were not provided until the end of the study.

https://doi.org/10.1017/ice.2016.107 Published online by Cambridge University Press

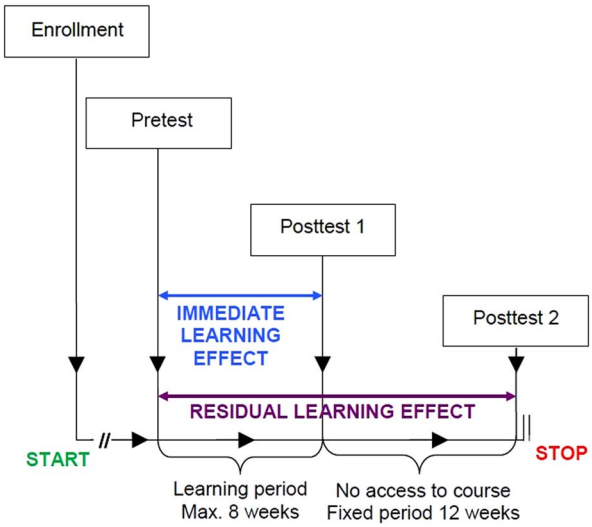

FIGURE 1. Study path. Study website open for course enrollment: October 30, 2010 to December 31, 2011. Final date to submit posttest T1: March 31, 2012. Final date to submit posttest T2: July 15, 2012. Study closed: July 15, 2012.

Study Time Measurement

Depending on the participant's prior knowledge, it was estimated that it would take 3–5 hours to master the course. Each participant's actual study time was automatically logged. Time-outs requiring an additional log in occurred following 5 minutes of computer inactivity and with a warning popped up on the screen whenever such a timeout was near.

Dropout Analysis

Following the end of the study, a 1-question survey was e-mailed to all participants who had not completed the entire study path to identify their reasons for opting out. The participants were offered 14 answering options to choose from to indicate the reasons for not completing the study. They could indicate as many answering options as applicable for their individual situation, or they could complete the reason in written text.

Statistical Analysis

For statistical analysis, SPSS for Windows 20.0 (IBM, Armonk, New York) was used. Tests were 2-tailed, and statistical significance was set at $P < 0.05$. Continuous variables with non-normal distribution are described as median (interquartile range; IQR). Univariate analysis was performed using the Mann-Whitney U test, Friedman test, or Kruskal-Wallis test as appropriate. For data analysis, the continuous variables "age" and "study time" were conveniently categorized in quartiles. The immediate learning effect was calculated by subtracting the T0 scores (%) from the T1 scores; the residual learning effect was calculated by subtracting the T0 scores from the T2 scores.

Multivariate linear regression analysis using the "Enter" method was conducted to assess independent relationships with immediate and residual learning effects. To avoid spurious associations, variables with a plausible relationship with learning effects and/or a statistical relationship in univariate analysis ($P < .20$) were included in the regression model. Multicollinearity was assessed. A stepwise elimination of variables with $P > .15$ was predefined to develop the final model.

To evaluate the course's effect in relation to human development level of a participant's country, the 2011 Education and Health Human Development Report of the United Nations Development Program was used to ranks countries into very high, high, medium, or low with regard to the human development index (HDI).[20]

Data were analyzed by S.L. and S.B. and were reviewed by a biostatistician at Ghent University.

Ethical Considerations

Upon enrollment, informed consent was given by ticking a box in the electronic registration form. The study was reviewed and approved by the ethics committee at Ghent University Hospital (registration codes B67020072039 and B67020108358).

RESULTS

Face Validity and Usability of the Course

All SUMI[16] items scored well above the expected average score of 50. Because they demonstrated user satisfaction with the course in general as well as with each of its subdimensions measured (Table 1), no software adaptations were made following this study.

Description of the Sample

A total of 3,587 HCWs representing 79 nationalities enrolled. Of these, 2,590 HCWs (72.2%) submitted T0; 1,410 HCWs (39.8%) actually studied the course and submitted T1; and 1,011 HCWs (28.2%) also submitted T2, thus completing the entire study path. The study flow chart is shown in Figure 2; participant characteristics are listed in Table 2.

The median study time (n = 1,410) was 194 minutes (IQR, 96–306 minutes). Convenient grouping of this variable according to its quartiles resulted in the following categories: <100 minutes (median 45 minutes; IQR, 24–70 minutes; n = 371), 100–200 minutes (median, 156 minutes; IQR, 127–178 minutes; n = 353), 201–300 minutes (median, 243 minutes; IQR, 223–269 minutes; n = 318), and

https://doi.org/10.1017/ice.2016.107 Published online by Cambridge University Press

>300 minutes (median, 405 minutes; IQR, 344–502 minutes; n = 368).

The median age of the 1,410 participants was 33 years (IQR, 28–40 years). This variable was conveniently categorized based on its quartiles as follows: <30 years (median, 26 years; IQR, 23–28 years; n = 441), 30–35 years (median, 32 years; IQR, 31–34 years; n = 429), 36–40 years (median, 38 years; IQR, 36–39 years; n = 210), and >40 years (median, 46 years; IQR, 43–50 years; n = 330).

Participants included 1,034 ICU nurses, 267 clinical nurse specialists, 261 general care nurses, 189 intensivists, 182 microbiologists, 115 head nurses, 115 nurse practitioners, 100 nursing students, 98 pharmacists, 73 emergency room nurses, 71 anaesthesiologists, 41 other physicians, 18 physician trainees, 8 respiratory therapists, 6 paramedics, and 4 physiotherapists.

TABLE 1. Results of Software Usability Measurement Inventory (SUMI) Testing

SUMI Dimensions	Mean Score (on 100)	Standard Deviation
Global	64.14	5.58
Affect	68.14	4.61
Efficiency	66.94	6.39
Control	60.18	5.96
Learnability	59.74	7.97
Helpfulness	58.50	5.06

Test Scores and Learning Effects

The overall median score at T0 was 52% (IQR, 44%–62%; n = 2,590), increased to 80% (IQR, 68%–88%) at T1 (n = 1,410), and was 74% (IQR, 64%–84%) at T2 (n = 1,011). Among the participants who completed the entire study path (n = 1,011), median scores were 54% (IQR, 46%–64%) at T0, 82% (IQR, 72%–90%) at T1, and 74% (IQR, 64%–84%) at T2. Table 2 shows the median scores according to student characteristics and related learning effects.

The overall immediate learning effect was 24% (IQR, 12%–34%; $P < .001$; n = 1,410), and the overall residual learning effect was 18% (IQR, 8%–28%; $P > .001$; n = 1,011). The immediate learning effect obtained by the students who completed the entire study path was 21% (IQR, 14%–34%; $P < .001$; n = 1,011).

For all course topics, positive immediate and residual learning effects were found (Table 3). Gains in knowledge increased with study time. The immediate learning effect reached a maximum at 200 study minutes (28%), while the residual effect was greater once study time exceeded 300 minutes (Table 2).

Multivariate linear regression (Table 4) identified longer study time, longer work experience, and living in a country with high or very high HDI as being associated with a better immediate learning effect; a higher score on the pretest, female gender, and higher age category were independently associated with lower learning effects ($R^2 = 0.36$).

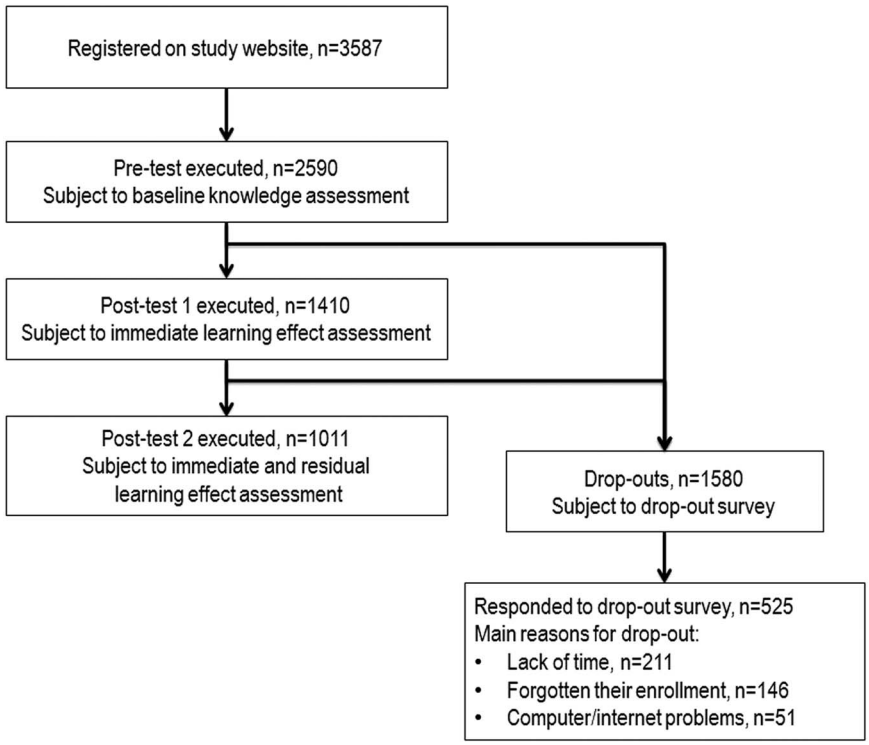

FIGURE 2. Study flow chart.

https://doi.org/10.1017/ice.2016.107 Published online by Cambridge University Press

TABLE 2. Median Test Scores and Learning Effects According to Learner Characteristics

	Pretest[a] (n = 2,590), % (IQR)	n	Pretest[b] (n = 1,410), % (IQR)	n	Pretest[c] (n = 1,011), % (IQR)	n	Posttest T1 (n = 1,410), % (IQR)	Immediate Effect[d] (n = 1,410), % (IQR)	*P* Value[e]	n	Posttest T2 (n = 1,011), % (IQR)	Residual Effect[f] (n = 1,011), % (IQR)	*P* Value[g]	n
Gender									.14				<.001	
Male	58 (48–66)	515	60 (50–66)	226	60 (50–66)	168	82 (68–91)	22 (10–32)		226	72 (63–80)	12 (4–20)		168
Female	52 (44–60)	2075	54 (44–62)	1184	54 (46–62)	843	80 (68–88)	24 (12–34)		1184	76 (64–86)	20 (8–30)		843
Age, y									.02				.003	
<30	48 (40–56)	915	50 (40–58)	441	50 (40–58)	275	76 (62–86)	24 (8–35)		441	70 (58–82)	20 (8–30)		275
30–35	52 (44–62)	746	54 (46–62)	429	54 (46–62)	322	82 (68–90)	24 (12–34)		429	76 (66–86)	20 (8–32)		322
36–40	56 (46–64)	369	56 (48–66)	210	58 (50–68)	158	82 (72–89)	22 (14–30)		210	75 (68–84)	15 (6–24)		158
>40	58 (50–66)	560	58 (50–66)	330	58 (50–66)	256	82 (70–90)	22 (10–32)		330	78 (68–86)	16 (6–26)		256
Experience, y									.19				.80	
<1	44 (36–52)	225	44 (36–54)	103	44 (36–54)	55	70 (54–82)	22 (6–36)		103	64 (52–76)	18 (6–28)		55
1–5	50 (40–58)	666	50 (42–58)	321	50 (42–58)	214	78 (64–88)	26 (10–36)		321	72 (60–81)	20 (8–30)		214
6–10	54 (46–62)	507	54 (46–62)	287	54 (46–62)	203	78 (68–88)	24 (12–32)		287	72 (64–84)	18 (8–28)		203
>10	56 (48–64)	1192	56 (48–66)	699	58 (48–66)	58	82 (72–90)	22 (12–32)		699	78 (68–86)	18 (8–28)		58
Profession									.10				.14	
Nurse	52 (44–60)	1865	54 (46–62)	1046	54 (46–62)	739	80 (68–88)	24 (12–34)		1046	76 (64–84)	18 (8–28)		739
Physician	60 (54–68)	309	60 (54–66)	125	60 (54–66)	86	84 (74–92)	24 (12–32)		125	75 (68–80)	14 (8–20)		86
Student	44 (36–52)	118	44 (32–52)	60	46 (39–54)	40	77 (57–86)	30 (11–42)		60	64 (53–76)	18 (6–30)		40
Other	52 (42–62)	298	54 (46–64)	179	54 (46–64)	146	78 (66–88)	22 (12–30)		179	76 (66–84)	17 (8–28)		146
Setting									.02				<.001	
ICU & related	54 (46–62)	1661	56 (48–64)	878	56 (48–64)	628	80 (68–88)	22 (12–32)		878	74 (64–84)	16 (6–26)		628
Non–ICU	50 (42–60)	929	52 (42–62)	532	52 (42–62)	383	80 (68–88)	24 (12–34)		532	78 (66–84)	20 (8–32)		383
Study time, min									<.001				<.001	
<100	NA	NA	54 (44–64)	371	56 (46–64)	191	68 (54–82)	10 (2–22)		371	70 (58–84)	10 (2–24)		191
101–200	NA	NA	56 (46–64)	353	56 (48–64)	276	82 (68–89)	22 (14–32)		353	72 (62–82)	14 (6–24)		276
201–300	NA	NA	54 (44–62)	318	54 (46–62)	241	82 (74–90)	28 (18–36)		318	74 (64–82)	18 (8–28)		241
>300	NA	NA	52 (46–62)	368	52 (46–60)	303	84 (76–90)	28 (20–36)		368	80 (70–88)	24 (16–34)		303
HDI									.43				.28	
Low & medium[h]	54 (46–64)	155	56 (48–64)	74	54 (48–64)	51	78 (66–88)	22 (6–33)		74	72 (66–80)	16 (6–26)		51
High &very high[i]	52 (44–62)	2435	54 (46–62)	1336	54 (46–64)	960	80 (68–88)	24 (12–34)		1336	76 (64–76)	18 (8–28)		960

NOTE. IQR, interquartile range; n, no. of participants; ICU, intensive care unit; NA, not applicable; HDI, human development index. Data are reported as median % (IQR). For study time and age data, intervals are based on quartiles.

[a]Median pretest scores (IQR) of participants who submitted only the pretest.

[b]Median pretest scores (IQR) of participants who submitted pretest + posttest T1,

[c]Median pretest scores (IQR) of participants who submitted pretest, posttest T1 + posttest T2 (entire study path).

[d]Immediate effect = Δ pretest – posttest T1.

[e]*P* value indicating difference in immediate learning effect between subgroups.

[f]Residual effect = Δ pretest – posttest T2.

[g]*P* value indicating difference in residual learning effect between subgroups.

[h]Low HDI = participants from Afghanistan, Angola, Bangladesh, Pakistan, Sudan. Medium HDI = participants from Egypt, El-Salvador, Honduras, India, Jordan, Occupied Palestinian Territory, Peru, Philippines, South Africa, Thailand.

[i]High HDI = Participants from Bolivarian Republic of Venezuela, Brazil, Bulgaria, Colombia, Cuba, Ecuador, Former Yugoslav Republic of Macedonia, Georgia, Islamic Republic of Iran, Kuwait, Malaysia, Mexico, Romania, Russian Federation, Saudi Arabia, Turkey, Ukraine. Very high HDI = participants from and Argentina, Australia, Austria, Belgium, Canada, Chile, Croatia, Cyprus, Denmark, Estonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, The Netherlands, New Zealand, Norway, Poland, Portugal, Singapore, Spain, Sweden, Switzerland, the United Arab Emirates, the United Kingdom, and the United States.

TABLE 3. Median Test Scores and Learning Effects for the Total Course and Per Category of Questions

	Pretest[a] (n = 2,590), % (IQR)	Pretest[b] (n = 1,410), % (IQR)	Pretest[c] (n = 1,011), % (IQR)	Posttest T1 (n = 1,410), % (IQR)	Immediate Effect[d] (n = 1,410), % (IQR)	Posttest T2 (n = 1,011), % (IQR)	Residual Effect[e] (n = 1,011), % (IQR)
Total course (50Q)	52 (44–62)	54 (46–62)	54 (46–64)	80 (68–88)	24 (12–34)	74 (64–84)	18 (8–28)
CAUTI (8Q)	50 (38–63)	50 (38–75)	50 (38–75)	88 (63–100)	25 (13–38)	75 (63–88)	13 (0–38)
CLABSI (11Q)	45 (36–67)	55 (36–64)	36 (55–64)	82 (64–91)	27 (9–36)	73 (55–91)	18 (0–36)
VAP (10Q)	50 (40–70)	60 (40–70)	60 (40–70)	80 (70–90)	20 (10–40)	80 (70–90)	20 (0–30)
SSI (6Q)	33 (17–50)	33 (17–50)	33 (17–50)	84 (50–100)	33 (17—67)	67 (50–83)	17 (0–50)
Hand hygiene (10Q)	60 (50–70)	60 (50–70)	60 (50–70)	70 (60–80)	10 (0–20)	70 (60–80)	10 (0–20)
Theoretical questions (7Q)	43 (29–57)	43 (29–57)	43 (29–57)	71 (57–86)	29 (14–43)	71 (57–86)	14 (0–43)
Practical questions (43Q)	53 (47–63)	56 (47–65)	56 (49–65)	81 (70–88)	21 (12–33)	77 (65–86)	16 (7–28)

NOTE. n, no. of participants; IQR, interquartile range; Q, questions; CAUTI, catheter-associated urinary tract infection; CLABSI, central line-associated bloodstream infection; VAP, ventilator-associated pneumonia; SSI, surgical site infection. Data are reported as median % (IQR).
[a]Median pretest scores (IQR) of participants who submitted only the pretest.
[b]Median pretest scores (IQR) of participants who submitted pretest + posttest T1.
[c]Median pretest scores (IQR) of participants who submitted pretest, posttest T1 + posttest T2 (entire study path).
[d]Immediate effect = Δ pretest – posttest T1.
[e]Residual effect = Δ pretest – posttest T2.
P value for all subgroup analyses: $P < .001$.

TABLE 4. Multivariate Linear Regression Analysis for Independent Relationships with Learning Effects

	B ± Standard Error	95% Confidence Enterval	*P* Value
Immediate Learning Effect[a]			
Median score on pretest	−1.06% ± 0.05	−1.17–(−0.96)	<.001
Study time (per class of increase)[b]	4.98% ± 0.30	4.40–5.57	<.001
Female gender	−2.62% ± 0.93	−4.46–0.78	.005
Work experience (per class of increase)[c]	1.25% ± 0.49	0.30–(−2.21)	.01
High & very high HDI	2.60% ± 1.52	−0.38–(−5.58)	.09
Age (per class of increase)[d]	−0.86% ± 0.44	−1.71–0.003	.05
Residual Learning Effect[e]			
Median score on pretest	−1.18% ± 0.07	−1.32–(−1.04)	<.001
Study time (per class of increase)[b]	3.18% ± 0.40	2.40–3.96	<.001
Female gender	2.60% ± 1.16	0.32–4.89	.02
Work experience (per class of increase)[c]	1.57% ± 0.47	0.65–(−2.49)	.001

NOTE. ICU, intensive care unit; HDI, human development index.
[a]$R^2 = 0.36$.
[b]Study time <100 min, 101–200 min, 201–300 min, or >300 min.
[c]Work experience <1 year, 1–5 years, 6–10 years, or >10 years.
[d]Age <30 y, 30–35 y, 36–40 y, or >40 y.
[e]$R^2 = 0.29$.

For the residual effect, longer study time, female gender, and longer work experience were identified as independently associated with better learning effects; a higher score on the pretest and higher age category were associated with lower effects ($R^2 = 0.29$). Multicollinearity analysis detected no correlations between the variables entered.

Dropout Analysis

Of all 1,579 dropouts contacted, 525 completed the survey (33% response rate). In addition to a lack of time (n = 211; 40%), the main reasons for opting out included having forgotten course enrollment (n = 146; 28%), problems with computer or Internet connection (n = 52; 10%), length of the study path (n = 21; 4%), and unavailability of the course in the respondent's mother tongue (n = 9; 1%).

DISCUSSION

In the present study, we found that limited time invested in studying an e-course on the essentials of HAI prevention with good usability and exercises for self-evaluation yielded

https://doi.org/10.1017/ice.2016.107 Published online by Cambridge University Press

significant increases in immediate (+24%) and residual (+18%) learning effects among HCWs. Although the course was originally developed for ICU professionals, it also showed to benefit HCW in non–ICU-related settings.

Cook et al[21] systematically reviewed 126 articles published between 1990 and 2007 that evaluated knowledge outcomes of Internet-based instructional methods compared to no intervention. Overall, e-learning improved knowledge by 12%. Our study resulted in an overall immediate learning effect of 24%, thereby doubling the expected improvement. However, our students were volunteers, and selection bias might have influenced our results. Our participants may have been particularly motivated or interested in the topic, and the most motivated or interested may have completed the entire study path, thus generating better learning effects than if participation had been imposed on a random sample. Yet, during the study course, numerous clinicians indicated that they participated specifically to obtain the certificate of participation issued by the ESICM. This motive for participation might at least partially alleviate selection bias caused by voluntary enrollment. Also, we found that greater prior knowledge was associated with lower immediate and residual learning effects. This can be considered a logical finding: the greater the prior knowledge, the less room for improvement. If these participants' prior knowledge was higher than that of the general population of HCWs, learning effects in a random sample might exceed those identified in the current cohort.

Interpretation of the results in association with participant characteristics (Table 2) shows that males and females obtained identical immediate learning results ($P = .14$). Residual effects were, however, significantly higher among women ($P = .001$; Table 2), and men displayed a greater decrease in knowledge after 3 months without course access (−10%). The current study did not focus on gender differences, and more research into the relationship between healthcare professionals' gender and learning styles, preferences, and outcomes might help to explain these findings.

Physicians and nurses demonstrated identical immediate learning effects (24%). Physicians nevertheless obtained higher crude pretest and posttest T1 scores with somewhat narrower interquartile ranges, which might be suggestive for a more common general knowledge of EBGs for HAI prevention than among nurses. Not unexpectedly, trainees obtained the lowest pretest scores and the highest immediate learning effect (30%). Their scores on posttest T1 (77%), as well as the scores of pharmacists, microbiologists, respiratory therapists, and paramedics (78%, other HCWs) were relatively low compared with physicians and nurses (84% and 80%, respectively). This result and the finding that more experienced participants obtained better scores on the pretest than their less experienced colleagues suggest a potential positive association between knowledge and daily practice experience.

Of all course topics (Table 3), SSI prevention was associated with the lowest baseline test scores and the highest immediate learning effect. Possibly, HCWs involved in surgical patient care are specifically familiar with this problem compared with those working in other types of settings. Remarkably, the limited learning effects and relatively low crude posttest scores obtained for the topic of hand hygiene reflect the challenge of finding an effective educational approach to increase HCW interest in hand hygiene guidelines and, consecutively, compliance.

The dropout rate from our course was high. Of all HCWs enrolled, <40% actually studied the course. Isolation of e-learners has been identified as a common reason for high dropout rates.[22] Our dropout survey identified a lack of time as the main reason for opting out. Because our sample merely consisted of volunteers involved in inpatient care, a high dropout rate was hardly unexpected; work, family life and personal commitments are easily and understandably prioritized over continuing eduation. Potentially, dropouts were less motivated than HCWs who completed the entire study, which may have contributed to the positive study results.

Additional research comparing different web-based interventions is needed to elucidate how to implement e-learning most effectively. In the meantime, our study suggests that moderate time invested in a low-cost e-course with good usability features and exercises for self-evaluation can enhance knowledge on HAI prevention. We therefore encourage institutional decision makers and professional societies to consider translating their recommendations in e-learning modules in parallel with published guidelines.

ACKNOWLEDGMENTS

The authors wish to acknowledge the valuable help of Prof. Jurek Kirakowski, School of Applied Psychology, University College Cork, Ireland, for free use of the SUMI software to evaluate the course's usability and for the related data analysis. We thank Prof. Georges Van Maele at University of Ghent for reviewing our data analysis. We are grateful to the VVIZV and the ESICM for endorsing the study and all support, and to all professional organizations that supported our recruitment of participants for this project. Last but not least, we sincerely thank all HCWs who participated in the project.

Financial support: This study was supported by a doctoral research grant from University College Ghent and an unrestricted grant from the ESICM and Edwards (ECCRN-Edwards Nursing Science Award 2008). The study was endorsed by the ESICM. Funding sources had no involvement in the design or analysis of this study.

Potential conflicts of interest: All authors report no conflicts of interest relevant to this article.

Address correspondence to Sonia Labeau, University College Ghent, Faculty of Education, Health and Social Work, 9000 Ghent, Belgium (sonia.labeau@hogent.be).

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/ice.2016.107

REFERENCES

1. Yokoe DS, Classen D. Introduction: Improving patient safety through infection control: a new healthcare imperative. *Infect Control Hosp Epidemiol* 2008;29:S3–S11.

2. AHRQ's efforts to prevent and reduce healthcare-associated infections. Pub No. 09-P013. Agency for Healthcare Research and Quality (AHRQ) website. http://www.ahrq.gov. Published September 2009. Accessed February 4, 2011.
3. Roberts RR, Scott RD, 2nd, Hota B, et al. Costs attributable to healthcare-acquired infection in hospitalized adults and a comparison of economic methods. *Med Care* 2010;48:1026–1035.
4. Umscheid CA, Mitchell MD, Doshi JA, Agarwal R, Williams K, Brennan PJ. Estimating the proportion of healthcare-associated infections that are reasonably preventable and the related mortality and costs. *Infect Control Hosp Epidemiol* 2011;32:101–114.
5. O'Grady NP, Alexander M, Burns LA, et al. Guidelines for the Prevention of Intravascular Catheter-related Infections. *Clin Infect Dis* 2011;52:e162–e193.
6. Yokoe DS, Mermel LA, Anderson DJ, et al. A compendium of strategies to prevent healthcare-associated infections in acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:S12–S21.
7. Rello J, Lorente C, Bodì M, Diaz E, Ricart M, Kollef MH. Why do physicians not follow evidence-based guidelines for preventing ventilator-associated pneumonia? A survey based on the opinions of an international panel of intensivists. *Chest* 2002;122:656–661.
8. Ricart M, Lorente C, Diaz E, Kollef MH, Rello J. Nursing adherence with evidence-based guidelines for preventing ventilator-associated pneumonia. *Crit Care Med* 2003;31:2693–2696.
9. Blot SI, Labeau S, Vandijck DM, Van Aken P, Claes B. Evidence-based guidelines for the prevention of ventilator-associated pneumonia. Results of a knowledge test among intensive care nurses. *Intensive Care Med* 2007;33:1463–1467.
10. Labeau S, Vandijck D, Rello J, et al. Evidence-based guidelines for the prevention of ventilator-associated pneumonia: results of a knowledge test among European intensive care nurses. *J Hosp Infect* 2008;70:180–185.
11. Labeau S, Witdouck S, Vandijck D, et al. Nurses' knowledge of evidence-based guidelines for the prevention of surgical site infection. *Worldviews Evid Based Nurs* 2010;7:16–24.
12. Labeau SO, Vandijck DM, Rello J, et al. Centers for Disease Control and Prevention guidelines for preventing central venous catheter-related infection: results of a knowledge test among 3405 European intensive care nurses. *Crit Care Med* 2009;37:320–323.
13. Bero L, Grilli R, Grimshaw JM, Harvey E, Oxman AD, Thomson MA. Closing the gap between research and practice: an overview of systematic reviews of interventions to promote implementation of research findings by health care professionals. *BMJ* 1998;317:465–468.
14. Reime MH, Harris A, Aksnes J, Mikkelsen J. The most successful method in teaching nursing students infection control—E-learning or lecture? *Nurs Educ Today* 2008;28:798–806.
15. Choules AP. The use of elearning in medical education: a review of the current situation. *Postgrad Med J* 2007;83:212–216.
16. Kirakowski J, Corbett M. SUMI: the Software Usability Measurement Inventory. *Br J Educ Technol* 1993;24:210–212.
17. Swygert KA, Balog KP, Jobe A. The impact of repeat information on examinee performance for a large-scale standardized-patient examination. *Acad Med* 2010;85:1506–1510.
18. Labeau S, Vandijck DM, Claes B, Van Aken P, Blot SI, executive board of the Flemish Society for Critical Care N. Critical care nurses' knowledge of evidence-based guidelines for preventing ventilator-associated pneumonia: an evaluation questionnaire. *Am J Crit Care* 2007;16:371–377.
19. Labeau S, Vereecke A, Vandijck DM, Claes B, Blot SI, executive board of the Flemish Society for Critical Care N. Critical care nurses' knowledge of evidence-based guidelines for preventing infections associated with central venous catheters: an evaluation questionnaire. *Am J Crit Care* 2008;17:65–71; quiz 72.
20. Human Development Reports. United Nations Development Program website. http://hdr.undp.org. Published 2015. Accessed April 22, 2016.
21. Cook DA. The failure of e-learning research to inform educational practice, and what we can do about it. *Med Teach* 2009;31:158–162.
22. Ellaway R, Masters K. AMEE Guide 32: e-Learning in medical education Part 1: Learning, teaching and assessment. *Med Teach* 2008;30:455–473.