Pilot Study of Educational Gaming to Improve Adherence to an End-Tidal Carbon Dioxide Monitoring Protocol

Taylore D. Jansen, RN, BSN, CCRN; Sonja Stutzman, PhD; Christine Yu, RN, BSN; David Parry, BA; and DaiWai M. Olson, PhD, RN, CCRN, FNCS

abstract

**Background:** End-tidal carbon dioxide (ETCO2) monitoring is an important part of patient care. Understanding and interpreting ETCO2 wavelengths can be a challenge. This pilot study explored the efficacy of a novel approach to educating clinicians on ETCO2 monitoring via game theory.

**Method:** A video game application for ETCO2 monitoring was developed. Clinicians were encouraged to play the game over a 3-month period. Compliance with the ETCO2 protocol was compared in a random selection of patients admitted before, during, and after the intervention.

**Results:** Thirty-eight clinicians completed the pre- and posttest, with a significant difference in test scores ($p = .03$). The intervention was associated with higher adherence to the ETCO2 protocol before and after the intervention ($p < .05$).

**Conclusion:** The availability of new technologies has created opportunities to develop new approaches to educate clinicians. This study showed that the use of a game improved adherence to the ETCO2 protocol.


End-tidal carbon dioxide (ETCO2) monitoring is potentially life-saving when used in the hospital setting, as it can quickly relay vital information to health care professionals (HCPs) about the patient’s current condition (Pantazopoulos et al., 2015; Takahashi et al., 2014). However, numerous HCPs lack the knowledge and understanding required to utilize ETCO2 monitoring to its fullest potential (Carlisle, 2015). This study sought to educate HCPs on ETCO2 monitoring and interpretation, as well as to increase adherence to the hospital’s ETCO2 monitoring policies through a gaming approach to education.

**BACKGROUND**

ETCO2 monitoring is a noninvasive measurement tool that utilizes waveform capnography to provide an estimate of partial pressure of CO2 (Hartmann, Farris, Di Gennaro, & Roberts, 2015). Use of ETCO2 monitoring has increased in the hospital setting with mechanically ventilated patients, those using patient-controlled analgesia (PCA) pumps, and patients undergoing procedural sedation or anesthesia (Conway, Douglas, & Sutherland, 2016; Hartmann et al., 2015; Nassar & Schmidt, 2016). Monitoring ETCO2 provides the HCP with valuable information regarding the adequacy of patient ventilation, acid–base balance, and perfusion to vital organs.

**Importance of ETCO2 Monitoring**

Many patients receive pain medications through the use of PCA pumps, which allow the patient to self-deliver a preset dose of intravenous pain medication with the push of a button (Hartmann et al., 2015). Although PCA...
pumps are programmed with ordered doses and intervals with the intent of delivering safe doses of pain medication, some patients may still experience an adverse effect of opioid pain medication. Hypoventilation and other respiratory distress signals can be detected via ETCO2 monitoring. Previous studies show that ETCO2 monitoring policies alert HCPs of respiratory decline up to 2 hours sooner than the standard pulse oximetry (Maddox & Williams, 2012). Effective use of ETCO2 monitoring requires baseline knowledge of normal ETCO2 ranges, recognition of normal versus abnormal waveforms, and understanding of treatment for abnormalities. Many HCPs do not receive extensive formal training on ETCO2 monitoring.

Electronic games have become common place in today’s generation. These games contain high-quality graphical user interface (GUI) systems and motivate the player through successively more difficult challenges (i.e., levels) that engage the user. Two concepts—game-based-learning, which is the use of games for educational purposes, and gamification, which is the use of rewards and incentives—are frequently used in facilitating learning. These concepts give rise to technology-enhanced active learning (TEAL). Advances in technology led to the development of specialized mannequins equipped with human-like functions, such as pulses, lung sounds, blinking eyes, and the ability to speak. Simulations are used to practice decision making in a nonthreatening environment and now are commonplace in the education of health care professionals. Simulations also bolster confidence, improve assessment skills, and encourage teamwork and collaboration (Dankbaar et al., 2016; Durham & Alden, 2008). In a study relating to the use of simulation in the health care setting to educate health care workers, researchers showed the use of bedside simulated mock codes can be helpful in increasing confidence and experience in pediatric resident physicians (van Schaik, Von Kohorn, & O’Sullivan, 2008).

**Knowledge and Comfort of Monitoring**

ETCO2 monitoring is not yet widely used in all areas of the hospital. One study conducted in various hospitals found that two intensive care units and one emergency department the 10 units surveyed used little to no ETCO2 monitoring (Langhan, Kurtz, Schaeffer, Asnes, & Riera, 2014). Health care providers demonstrated a lack of knowledge in the concepts of ventilation versus oxygenation, indications for ETCO2 monitoring in nonintubated patients, and differences in pulse oximetry monitoring versus ETCO2 monitoring. Participants did not feel comfortable using ETCO2 monitoring and stated they had not received adequate training (Langhan et al., 2014).

There is little information in the literature regarding HCP’s knowledge of ETCO2 monitoring; however, the previous literature clearly indicates a lack of knowledge among HCPs (Anderson, 2006). This, in turn, prevents ETCO2 monitoring from being used to its maximum potential.

Clinical education is ongoing, and new techniques are needed to keep clinicians up to date on new evidence-based practices (Johnston, Boyle, MacArthur, & Manion, 2013). Traditionally, students and HCPs receive much of their formal education in a lecture hall setting in conjunction with assigned reading material. Advances in technology have increased the use of interactive, competitive games, and simulations are replacing the traditional, written documents to educate health care professionals. Simulations are valuable adjuncts to traditional, written documents for use in the education of health care professionals. This study aims to determine whether an educational game on ETCO2 monitoring increases HCP knowledge of ETCO2 monitoring in the neurocritical care setting and adherence to the hospital’s ETCO2 clinical protocol.

**METHOD**

This is a nonrandomized pilot study of ETCO2 education using a gaming intervention. The study was approved by the institutional review board. Documentation of ETCO2 was abstracted from the electronic medical record (EMR). The HCPs were consented prior to participating in the study. The study was not externally funded and relied on volunteer support from an outside computer programmer (D.P.). The hospital protocol informs HCPs to use ETCO2 for all patients who require mechanical ventilation and all patients with PCA use. The HCPs were blinded to the primary outcome (documentation of ETCO2); HCPs were informed that the study examined ETCO2 knowledge (pretest and posttest knowledge scores). The outcome of adherence to hospital ETCO2 protocol was measured by data abstraction from the EMR. The knowledge outcome was measured by pretest–posttest scores from a didactic test of ETCO2 knowledge (Figure A; available in the online version of this article).

Fifty-three participants were recruited and consented from the neurocritical care unit (NCCU) at a large academic hospital. These 53 participants comprised RNS, respiratory therapists, and the assigned primary care providers (either physicians, nurse practitioners, or physician assistants). Members of the float pool, contract employees, and those in the orientation phase of their training were excluded from the study.

**Procedure**

Every phase of this study was approved by the institutional review board prior to execution. The study examined HCP behavior by comparing EMR documenta-
tion of ETCO2 use. Phase I was 3 months in duration and occurred prior to consent of any participants. A random sample of 44 EMRs were retrospectively abstracted for patients who required ETCO2 monitoring per unit protocol. Variables measured included the total number of participants, number of eligible participants, the total number of eligible participants who received ETCO2 monitoring, the number of hours each participant was eligible, and the number of hours each participant received ETCO2 monitoring.

Phase II, 3 months in duration, involved recruitment and consent of eligible participants, completion of the pretest, playing the game, and completion of the posttest. Participants were blinded to the hypothesis that the ETCO2 game resulted in increased adherence to the ETCO2 monitoring protocol. Phase II also included a review of 43 randomly selected EMR of patients who required ETCO2 monitoring. Phase III, was also 3 months in duration and involved a review of 44 randomly selected EMRs of patients who required ETCO2 monitoring.

**Intervention**

The intervention was based on gaming theory and was a short (time-limited) scenario-based game called So Long 2 Pong. The game was developed by David Parry, a Principal Software Engineer to Mutualink Inc. The game software was developed using Java on a cross-platform gaming engine allowing for multiple delivery form factors. The participants played the game on hospital computers while on shift (Figure B: available in the online version of this article). The game resembled a basketball court. The question, along with multiple choice answers, appeared at the top of the screen while basketballs labeled with the answer choices (A, B, C, D, or E) fell. Participants were instructed to catch the correct basketball by moving a basketball hoop. The So Long 2 Pong game was composed of two levels. The first level consists of 14 multiple choice questions pertaining to the use of ETCO2 monitoring, interpretation of ETCO2 values and waveforms, and the medical management following these interpretations. When the correct basketball was caught in the hoop, the participant’s score increased by 2 points on the score board. No points are deducted for incorrect answers during the first level. The second level consisted of the same 14 multiple choice questions. In the second level, 2 points were still awarded for correct answers; however, 2 points were also deducted for incorrect answers. Upon completion of level two, participants saw a “Congratulations” screen, indicating they successfully completed the game.

**RESULTS**

Data were entered into an electronic spreadsheet and then imported and analyzed using SAS® version 9.4 software. The game was played anonymously, and all forms were completed using the participant’s deidentified study number. All data were analyzed using the deidentified information. The study enrolled 53 participants: 36 RNs, eight respiratory therapists, and nine physicians, nurse practitioners, and physician assistants from the NCCU. Of these, 38 completed both the pretest and posttest and were included in the final analysis. There was a statistically significant improvement comparing the pretest mean of 6.39 (range = 0 to 13, SD = 3.2) to the posttest mean of 7.42 (range = 2 to 15, SD = 3.0) score (p = .03). The results showed a significant increase in clinicians’ knowledge after playing the technology-enhanced So Long 2 Pong educational game of ETCO2 monitoring. Because the study sought to preserve the anonymity of participants, there was no link to individual participant adherence to protocol or performance during the intervention. An omnibus test showed no significant differences between groups (p = .7581).

Data were abstracted from the EMRs of 130 patients (43 phase 1, 43 phase 2, and 44 phase 3) admitted to the same NCCU and requiring mechanical ventilation, PCA, or both. As shown in the Table, there was no difference in the mean number of hours of mechanical ventilation (p = .50), or PCA use (p = .59). Adherence was measured as the number of hours ETCO2 monitoring was documented as present divided by the number of hours for which ETCO2 was indicated. In the omnibus test across all three phases, there was no statistically significant difference in adherence to ETCO2 monitoring during mechanical ventilation (p = .14), nor PCA use (p = .62). Finally, the primary hypothesis was explored by dichotomizing the data to compare the preintervention (phase 1 and phase 2) to the postintervention (phase 3). The difference in compliance rates for the primary hypothesis of intervention adherence was statistically significant (p < .05).

**DISCUSSION**

The data from this pilot study support the concept of education using game playing as a potential mechanism to change adherence to an ETCO2 monitoring protocol. There was a statistically significant difference in adherence to the ETCO2 protocol in the NCCU after the teaching intervention was complete. In addition, the change was sustained 3 months after the intervention. These results are consistent with a growing body of literature supporting gaming theory as an educational tool (Elzein, Drenkard, Deyo, & Swartwout, 2015; Johnston et al., 2013). Because there was a statistically significant difference in adherence to ETCO2 protocol following completion of the game, it can be inferred that clinicians were more mo-
tivated to adhere to the ETCO2 protocol after playing the game.

This was a small pilot study that adapted a game-playing application available via the Internet. The use of TEAL as an educational tool is slowly being integrated into health care (Olson, Cohn, & Carlson, 2000; Petty, 2013). The lack of more robust results may reflect limitations associated with early development of the pilot study; many of these could easily be rectified if the study demonstrates efficacy. For example, during the intervention, the game sometimes froze (i.e., it stopped running). It was also noted that the game was only available through a USB (not Internet based) and could not be played on mobile devices such as smartphones and tablets. McCoy et al. (2015) identified that “glitches” are a major barrier to adoption of TEAL interventions. The So Long 2 Pong game supports the efficacy of investing in higher fidelity applications and can be adopted to explore other areas of teaching; however, such glitches may interfere with its acceptance and use.

Clinical education is ongoing, and new techniques are needed to keep clinicians up to date on new evidence-based practices (Johnston et al., 2013). Given how far technology has advanced in the past few decades, it’s important to continue to enhance teaching practices with the influx in technological advances. This study provided clinicians with a novel approach to learning about ETCO2 monitoring. The results showed a significant increase in clinicians’ knowledge after playing the technology-enhanced So Long 2 Pong educational game of ETCO2 monitoring. This is consistent with previous literature demonstrating simulation education and mock education as potentially helpful in teaching clinicians and highlighting simulation as a preferred method of learning, compared with traditional teaching strategies (van Schaik et al., 2008). Future research and education would be beneficial, specifically for patients who receive medication via PCA pumps, as these patients are at a higher risk for hypoventilation that would be detected via ETCO2 monitoring.

The intervention phase occurred over a 3-month period, which allowed ample time for clinicians to play the game. Some clinicians may have not participated in the So Long 2 Pong intervention until the last day of the intervention phase, which could explain why there was no differences between phase 1 and 2 when comparing this to phase 3. The statistically significant difference in phase 3 implies that the So Long 2 Pong intervention strategy has positive implications for training direct care clinicians, which can improve compliance with patient-related interventions and procedural policies.

### LIMITATIONS

Although the intervention supports TEAL as a potentially effective teaching strategy, there are limitations to the study. This study was conducted in a single hospital unit; therefore, the sample size of 53 was small and inadequate to make generalizations about the entire population of RNs, nurse practitioners, physician assistants, respiratory therapists, and physicians. Another limitation was time constraints. The game was designed with the intent to be played during normal work hours (i.e., brief, simple, and electronic). Feedback from participants revealed that finding time to play the game was difficult. The study lacked sufficient participant feedback on the posttest question.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Phase 1 (n = 43)</th>
<th>Phase 2 (n = 43)</th>
<th>Phase 3 (n = 44)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with mechanical ventilation (MV)</td>
<td>20 (46.5%)</td>
<td>19 (44.2%)</td>
<td>23 (52.3%)</td>
<td>.72</td>
</tr>
<tr>
<td>Hours patient received MV</td>
<td>87 (18.5 to 152.9)</td>
<td>127.5 (13.5 to 239)</td>
<td>93.9 (16.0 to 162.0)</td>
<td>.50</td>
</tr>
<tr>
<td>Hours ETCO2 documented during MV</td>
<td>75.7 (11.3 to 122.5)</td>
<td>103.3 (5.0 to 180.0)</td>
<td>80.8 (14.0 to 112.0)</td>
<td>.67</td>
</tr>
<tr>
<td>ETCO2 adherence for MV</td>
<td>66.4%</td>
<td>65.1%</td>
<td>83%</td>
<td>.14</td>
</tr>
<tr>
<td>Patients with patient controlled analgesia (PCA)</td>
<td>27 (62.8%)</td>
<td>29 (67.4%)</td>
<td>22 (50%)</td>
<td>.25</td>
</tr>
<tr>
<td>Hours of PCA use</td>
<td>40.4 (22.0 to 43.5)</td>
<td>35.6 (17.3 to 44.0)</td>
<td>31.3 (17.5 to 43.5)</td>
<td>.59</td>
</tr>
<tr>
<td>Hours ETCO2 documented during PCA</td>
<td>10.5 (0.0 to 19.0)</td>
<td>5.6 (0 to 7.0)</td>
<td>5.3 (0.0 to 4.0)</td>
<td>.33</td>
</tr>
<tr>
<td>ETCO2 adherence for PCA</td>
<td>24.2%</td>
<td>17.1%</td>
<td>16.2%</td>
<td>.62</td>
</tr>
<tr>
<td>Overall ETCO2 adherence</td>
<td>45%</td>
<td>37.4%</td>
<td>50.2%</td>
<td>.37</td>
</tr>
</tbody>
</table>

- The number of patients with MV and PCA are not mutually exclusive.
- Showing the mean (IQR) for the number of hours.
- Showing the percentage.
“How many times did you play the ETCO2 game?” If this study was replicated, it would be helpful to add a sign-in to the game to track the HCPs who played the game and the number of times the game was played.

Despite these limitations, this study examined a topic not widely discussed in the literature. Furthermore, this study introduced a novel method of education. Although many hospital systems currently rely on traditional education strategies, our experience utilizing TEAL with ETCO2 education supports its effectiveness. Additional research and more sophisticated GUI formats may further enhance the utility of TEAL in the clinical setting. The mobile electronic platform further provides an easy mechanism to share educational material with other institutions.

CONCLUSION
The study extends a growing body of TEAL interventions and demonstrates the efficacy of a high-technology, competitive, computer game as beneficial in serving as an alternative means of education in a hospital setting. Education games have the potential to promote clinical protocol adherence. Future research using gaming could be tailored to specific topics to help engage employees in learning.

REFERENCES
Pretest–Posttest Questions

1) What patients are required to have end-tidal carbon dioxide (ETCO2) monitoring while in the Neuro ICU?

2) I am confident in my knowledge and abilities in interpreting ETCO2 values and waveforms

3) I am confident in my ability to correctly interpret ETCO2 values/waveforms and anticipate specific treatments for said values/waveforms

4) I feel I have been thoroughly educated on ETCO2 monitoring

5) What can ETCO2 tell you about? Select all that apply.

6) What is the normal ETCO2 range?

7) Which segment(s) represent expiration? Select all that apply.

8) What does the following waveform represent?

9) Which of the following waveforms represents an airway occlusion?
10) Which of the following could contribute to a decreased ETCO2?

11) True or false: ETCO2 can be up to 5 mmHg less than PaCO2.

12) What is the minimum ETCO2 value that indicates chest compressions during cardiopulmonary resuscitation (CPR)

13) True or False: ETCO2 can only be monitored through an attachment that hooks up to the endotracheal (ET) tube.

14) Which of the following could contribute to an increased ETCO2 value? Select all that apply.

15) How many times did you play the ETCO2 game? *(only asked on posttest)
Figure B

Supplemental Digital Content 1: Screen Capture of the So Long 2 Pong Game

(Note. EtCO2 = end-tidal carbon dioxide.)