Instructional design affects the efficacy of simulation-based training in central venous catheterization

David F Feldon, Utah State University
Surgical Education

Instructional design affects the efficacy of simulation-based training in central venous catheterization

Christopher Craft, Ph.D.*a, David F. Feldon, Ph.D.b, Eric A. Brown, M.D.c

aPalmetto Learning, LLC, 7001 St Andrews Road, #322, Columbia, SC 29212, USA; bCenter for the Advanced Study of Teaching and Learning in Higher Education, University of Virginia, Charlottesville, VA, USA; cPalmetto Health – University of South Carolina School of Medicine Simulation Center, School of Medicine, University of South Carolina, Columbia, SC, USA

KEYWORDS: Simulator; Central venous catheterization; Cognitive task analysis; Instructional design; Training

Abstract

BACKGROUND: Simulation-based learning is a common educational tool in health care training and frequently involves instructional designs based on Experiential Learning Theory (ELT). However, little research explores the effectiveness and efficiency of different instructional design methodologies appropriate for simulations. The aim of this study was to compare 2 instructional design models, ELT and Guided Experiential Learning (GEL), to determine which is more effective for training the central venous catheterization procedure.

METHODS: Using a quasi-experimental randomized block design, nurse anesthetists completed training under 1 of the 2 instructional design models. Performance was assessed using a checklist of central venous catheterization performance, pass rates, and critical action errors.

RESULTS: Participants in the GEL condition performed significantly better than those in the ELT condition on the overall checklist score after controlling for individual practice time (F[1, 29] = 4.021, P = .027, Cohen’s d = .71), had higher pass rates (P = .006, Cohen’s d = 1.15), and had lower rates of failure due to critical action errors (P = .038, Cohen’s d = .81).

CONCLUSIONS: The GEL model of instructional design is significantly more effective than ELT for simulation-based learning of the central venous catheterization procedure, yielding large differences in effect size.

© 2014 Elsevier Inc. All rights reserved.
technology itself or post-use performance by learners. Documentation or analysis of the training methodology is often absent. This represents a major obstacle to the replication and generalizability of findings, because the instructional design (ID) becomes decoupled from the learning outcomes. This decoupling can weaken the argument that simulation has added value over traditional methods. Given the significant investment required to use simulation technologies and their increasing prevalence, medical educators should have access to research that will enable them to make informed decisions and to leverage these tools to maximal effect.

**Instructional design models**

ID refers to the conceptualization, development, implementation, management, and evaluation of processes and resources intended to facilitate learning. ID models are specific collections of these practices that are typically implemented in a systematic way to generate curricula and relevant supporting materials. They are typically linked to specific theories of learning that justify their respective approaches and use relevant research on learning processes and instructional effectiveness.

Experiential Learning Theory (ELT) is one such model that is frequently used as the basis for designing and examining simulation-based learning opportunities. It defines learning as a process of creating knowledge through transformational experience and can be characterized as a minimally guided model. At the outset of instruction, ELT directs learners to attempt to implement a procedure or process with which they are not yet familiar to observe the consequences of their actions. Following this step, it prescribes 3 subsequent phases: abstract conceptualization (mental organization of experiences), active experimentation (application of new skill), and reflective observation. Brief descriptions are presented in Table 1. Attempts to validate ELT have focused on the learning styles portion of the theory. However, there has not been an empirical validation of the model to date or direct comparisons with alternative models to compare efficacy.

In contrast, Guided Experiential Learning (GEL) provides a high degree of learner guidance during instruction, so each activity is highly structured, including explicit information about the targeted learning objective; the value of attaining the objective and risks of failing to do so; an overview of the training content and structure; explanations of the necessary concepts, processes, and principles; a demonstration of the target procedure; practice opportunities with diminishing levels of support provided to the student; and specific evaluative feedback. All GEL lessons share the same general structure designed to guide students’ cognitive processing to support learning. Instructions are sequenced according to the order in which they are applied in the field. When no specific order exists, instruction is sequenced with the easier aspects of the target task presented before more difficult ones. The standard lesson structure is described in Table 2. However, it should be noted that the final step in GEL, providing feedback, was not implemented during the present study, to maximize comparability with the ELT model.

Recent research reflects a disagreement about the optimal level of guidance provided to learners during instruction. Some researchers advocate greater degrees of learner autonomy that manifest as less direct explanations of procedures and concepts, as reflected in some problem-based learning approaches. In contrast, others argue that without explicit guidance on how to approach and resolve problems, learning and subsequent performance suffer.

In the present study, these 2 ID models were directly compared for efficacy in training participants to conduct a central venous catheterization (CVC) procedure using a simulator. The level of explicit guidance provided is the major difference between the 2 models.

**Instructional design research in health care simulation-based training**

Despite their widespread use in medical education, very little is known about the optimal use of health care simulations for training. In practice, the content taught by medical experts is typically based on individual preference and opinions rooted in the ways each were taught during training in medical school, residency, and practice. Because most health care educators are not formally trained in ID, a set of research-supported principles is needed that instructional designers can use when designing individual scenarios, complete courses, or assessment activities.

There are very few studies in the health care simulation literature that compare ID models in a head-to-head fashion. Many studies are conducted using problematic research designs, including a failure to use control groups against which to compare effectiveness, calling into question the validity of claims of simulation effectiveness.

In studies that do directly compare ID models, a new ID model is often compared with typical practice as a control.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The 4 modes of learning as described by experiential learning theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete experience (feeling)</td>
<td>Learners must involve themselves fully, openly, and without bias in new experiences.</td>
</tr>
<tr>
<td>Abstract conceptualization (thinking)</td>
<td>Learners must create concepts to integrate their observations into logically sound theories.</td>
</tr>
<tr>
<td>Active experimentation (doing)</td>
<td>Learners must use theories to solve new problems.</td>
</tr>
<tr>
<td>Reflective observation (watching)</td>
<td>Learners must reflect on their experiences from a variety of perspectives.</td>
</tr>
</tbody>
</table>
condition, which represents existing instruction as currently implemented in the institutional setting of the study. How-
however, differences in specific content may also exist. Vari-
tiations in content potentially equip learners with different foundations of knowledge. This, in turn, may lead to perfor-
mance variations that are independent of the differences asso-
ciated with simulator use or instructional approach.

Goals of this study

Using a common emergency care procedure, CVC, this study investigates the manner in which such training can be most effectively used to improve the adherence to the standard of care by medical practitioners performing this procedure. In the present study, we compared 2 ID models (ie, ELT and GEL) to determine which model is more effective at training inexperienced nurse anesthetists to successfully insert a central venous catheter using a mannequin-based simulator.

Hypotheses

The 2 hypotheses for the study were as follows: (1) After controlling for the influence of individual differences in practice time, the estimated marginal mean on the skills checklist will be significantly higher for the GEL group than for the ELT group. (2) Participants in the ELT condition will be more likely to fail the checklist assess-
ment because of either a score <70% or a critical action error.

Methods

Study design and setting

This study used a quasi-experimental design. Although participants could not be randomly selected, because of data collection from a single academic program, all participants were randomly assigned to a model (ELT or GEL), as seen in Table 1. Experts in the development and implemen-
tation of each ID model provided formative feedback and validated the instructional materials as strong examples of the respective models (Alice Kolb, co-originator of ELT with David Kolb and president of Experience Based Learning Systems, Inc, personal communication, 2010; Kenneth Yates, senior research associate at the University of Southern California Center for Cognitive Technology, directed by Richard E. Clark, where he contributed to the development of the GEL ID system, personal communication, 2010). Specific similarities and differences between these models are presented in Table 3. The instructional content used in each model was derived from a cognitive task analysis of the CVC procedure and corroborated by an expert clinician who performs this procedure in practice.

The study was conducted at the Palmetto Health – University of South Carolina School of Medicine Simulation Center (Columbia, SC). The simulation center consists of 6 mock hospital rooms complete with the same equipment found in the actual clinical environment. Each room is equipped with a flat-screen television or computer monitor connected to a computer behind 1-way glass, where the researcher observes the room. The researcher had control

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Guided experiential learning lesson structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Learning objective</td>
<td>Describe new abilities students will have, in what context, and to what standard when they finish this lesson.</td>
</tr>
<tr>
<td>b. Reason</td>
<td>Answer implied questions about value and utility such as “Why is learning to do this important to me?” “What value does it hold for me, my job, my mission, or my team?” and “What risk will I avoid if I learn it?”</td>
</tr>
<tr>
<td>c. Overview</td>
<td>Briefly describe the location of this lesson in the larger instructional sequence and the strategies to be used in the lesson.</td>
</tr>
<tr>
<td>d. Concepts, processes and principles</td>
<td>Review or introduce necessary background concepts, processes or principles required to implement procedure being taught.</td>
</tr>
<tr>
<td>e. Demonstration of procedure</td>
<td>The procedure being taught is demonstrated and accompanied by job aids that summarize the action and decision steps in the procedure.</td>
</tr>
<tr>
<td>f. Practice the procedure</td>
<td>Guided practice exercises simulate real problems in realistic contexts. Problems increase in complexity and variety through the progression of exercises. New problems will be cumulative by including elements dependent on knowledge from previous modules, allowing trainees to practice previously learned procedures. Guidance is gradually withdrawn or faded during practice as student use of procedures becomes more fluid and accurate.</td>
</tr>
<tr>
<td>g. Review practice and give feedback</td>
<td>Students must receive feedback on their practice that focuses on: a) what they accomplished that was correct, and (if necessary), b) how they need to adjust their procedure or strategy to complete their learning goals.</td>
</tr>
</tbody>
</table>
over the video instruction by controlling the computer in the observation area. The mock hospital rooms were equipped with microphones in the ceiling, permitting sound inside the room to be heard and recorded. The entire simulation encounter was recorded using an integrated system called SimCapture (B-Line Medical, LLC, Washington, DC), which records audio and video through 2 cameras. Participants were aware that study sessions were recorded, as is standard procedure at the simulation center. Additionally, there are signs posted in all simulation rooms indicating that all encounters may be videotaped.

The mannequin simulator used was a Laerdal IV Torso (Laerdal Medical, Stavanger, Norway) that can be cannulated in the internal jugular, subclavian, and femoral veins. The mannequin is filled with 2 L of artificial blood so that once the vein is cannulated, participants see proper blood return (ie, “flash”) in the needle and catheter. Experienced simulation specialists regularly inspected the mannequin to ensure that it was in proper working order and had sufficient supplies for each training encounter. Identical rooms, mannequins, and other equipment were used for both study arms.

The study was approved by the University of South Carolina internal review board, and all participants signed consent forms indicating that they understood all rights accorded to them during participation.

### Selection of participants

The sample for this study consisted of 32 participants enrolled in the University of South Carolina School of Medicine Graduate Program in Nurse Anesthesia, all of whom must demonstrate competence in performing CVC before graduation. The 2-year program matriculates 30 students per year, yielding a total enrollment of 60 students, of which the participating sample represented 53.3%. All the participants possessed valid certification as registered nurses with a variety of experience levels as clinicians. The majority of participants in this study were 1st-year students (n = 21), with the remainder enrolled in their 2nd year (n = 11). Participants from each year were randomly assigned to 1 of the 2 experimental models, with 10 1st-year students and 6 2nd-year students assigned to receive ELT instruction and the remaining 16 assigned to receive GEL instruction. The researchers obtained data from the participants about their levels of experience before the intervention. In preliminary analyses, year in program did not account for any differences in performance, so it was not included as a factor in the analyses.

### Interventions

When participants arrived at the simulation center, a researcher escorted them back to the study area. First, each participant was asked to fill out the entry survey. The participant was asked to wash his or her hands, wrists, and forearms as though the procedure were to be performed on a live patient. The researcher then led the participant into the mock hospital room, and the training video was started. Prerecorded instructional videos were used to ensure instructional consistency in each condition and accommodate the scheduling needs of participants. For the ELT group, the video indicated that the learner should begin with the case study. For the GEL group, the video began with a series of overviews followed by specific instruction on the procedure. Differences between the conditions were consistent with the differences highlighted in Table 3. It should be noted that individualized feedback on performance was not offered in either condition, to maximize comparability across conditions and minimize the opportunity for observer bias to influence participant performance.

The researcher observed participants through the 1-way glass to ensure that participants complied with the instructions provided during the training, which differed by condition. Noncompliance would have resulted in a participant’s data being excluded from analysis. However, none of the participants deviated from the instructions provided in the video.

### Methods and measurements

The primary instrument used in the study was a checklist for evaluating participants’ performance on the simulated
CVC task. The checklist included a section to record the time that certain events began and were completed. The video for both instructional conditions informed the participant to open the envelope containing the case study when he or she was ready to begin the evaluation. The starting and ending times of the evaluation case were recorded. Only the evaluation segment of the procedure was scored for the current study.

The checklist consisted of a list of the steps taken from the cognitive task analysis used to develop the instruction. While watching the video of a participant’s performance, the observer assigned a mark of 1 if the participant performed the step properly and a mark of 0 if he or she did not. The checklist included an area for the researcher to record relevant timed events, including the beginning and end of the patient encounter, the amount of time spent practicing the procedure, and the beginning and end times of the evaluation. Interrater reliability was established between the first and third authors with a Cohen’s k coefficient of .790. The full checklist can be found in the Appendix.

Outcomes

The performance checklist described was the primary outcome measure, providing data as both an aggregate score per participant and a total pass rate per condition. A sum of 11 of 15 possible points represented a passing score (~70%), predetermined by the general skill level of the participants, the difficulty of the procedure, and assessment standards common in medical education. However, if a participant made an error on either of 2 critical actions in the procedure, he or she failed, regardless of total score. Critical actions are defined as any action that when performed incorrectly would directly jeopardize a patient’s safety. In the present study, the 2 critical actions were observed: (1) any violation of the sterile field that would put the patient at risk for a central line–associated bloodstream infection and (2) releasing the guidewire after insertion, which could potentially result in migration of the guidewire into the vessel and toward the heart.

Analysis

Checklist scores were analyzed using 1-way, 1-tailed analysis of covariance (ANCOVA) with condition (ELT and GEL) as the independent variable, individuals’ practice time as the covariate, and total checklist score as dependent variable. Because the time allocated to practice can vary as a function of each individual rather than a fixed property of the ID model, it was considered a nuisance variable and used as a covariate in all relevant analyses. Pass rates and error rates were analyzed using Fisher’s exact test to determine whether these differed significantly between ID models. No significant differences were detected on the basis of participants’ year in the nurse anesthesia training program, so all analyses are reported using the participants pooled only by condition. SPSS version 17 (SPSS, Inc, Chicago, IL) was used for all statistical analyses.

Results

Comparison of checklist scores

The first hypothesis stated that after controlling for the influence of individual differences in practice time, the estimated marginal mean score on the skills checklist assessing proper insertion of the central venous catheter and maintenance of the sterile field would be significantly higher for the GEL group. The descriptive data indicate that the participants in the GEL condition spent less time in the learning portion of the study (mean, 50.88 ± 9.53 minutes) compared with ELT participants (mean, 62.25 ± 12.95 minutes) and more time practicing (mean, 43.13 ± 10.87 minutes; range, 19 to 58 minutes) than ELT participants (mean, 34.88 ± 14.76 minutes; range, 18 to 61 minutes). However, a 1-way, 2-tailed analysis of variance did not indicate a statistically significant relationship between ID model and total practice time (F[1, 31] = 3.241, P = .082).

Participants in the GEL model had higher mean scores (13.00 ± 1.10) on the checklist than those in the ELT condition (mean, 12.44 ± 1.59). After adjusting for differences in practice time, marginal means reflected a greater difference in favor of the GEL condition (adjusted mean ± SE, 13.19 ± .322) compared with the ELT condition (adjusted mean ± SE, 12.25 ± .322). A 1-way, 1-tailed ANCOVA with ID model as the independent variable, participants’ checklist scores as the dependent variable, and individual participants’ time spent on practice as the covariate was significant (F[2, 29] = 4.088, P = .0135), accounting for 22% of the variance. The ELT and GEL group mean checklist scores differed significantly (F[2, 29] = 4.021, P = .027), accounting for 12.2% of the variance independent of the covariate, with a large Coehens d effect size of .81 (Table 4).

Test of the second hypothesis: comparison of failure rates

The second hypothesis stated that participants in the ELT condition would be more likely to fail the checklist assessment because of either a score <70% or a critical action error. Overall, 4 ELT participants passed the checklist-based assessment, and 12 failed. In the GEL condition, 11 passed, and 5 failed. Using a 1-sided Fisher’s exact test, the distribution of pass and fail frequencies across conditions (2 × 2 contingency table) differed significantly from chance, with the GEL ID model yielding a higher pass rate (P = .016, Cohen’s d = 1.04). Of the 12 ELT participants who failed, 11 committed critical action errors. Of the 5 failing GEL participants, all committed critical action failures. A 1-sided Fisher’s exact test
indicated that this distribution differed significantly from chance ($P = .038$, Cohen’s $d = .87$).

**Comments**

Simulation-based activities are commonly used in health care training and are increasingly the focus of research in medical education. However, the design of the instruction that accompanies simulator-based training has received less attention. In this study, we compared the efficacy of 2 ID models commonly used in medical education that are based on different approaches to instruction: ELT and GEL. We hypothesized that, after controlling for individual differences in time spent practicing, participants in the GEL model would outperform those in the ELT model when performing a CVC procedure on a mannequin. The hypothesis was supported by significant differences in participants’ overall scores, pass rates, and critical action errors (violations of field sterility or releasing the CVC guidewire). The ID models differed primarily in the sequencing of instructional content and practice opportunities, reflecting the importance of instructional approach during simulator-based training for influencing performance outcomes.

ELT affords learners the opportunity to attempt the procedure once before watching video instruction. In contrast, GEL requires that learners receive highly explicit instruction before an attempt is made. Although ELT instruction does provide information to address errors made during performance of the procedure, in this case, the lack of instruction preceding an attempt is associated with more observed errors during the postinstruction assessment. This result is consistent with the findings in other educational research, which indicate that novices benefit most from highly explicit instruction and access to worked examples before practice.10,31

**Limitations**

The findings of this study are limited by several factors. First, the use of a specific simulator model and participants from a single program limit generalizability to other technologies and populations. Although there is nothing to indicate that the use of a different simulator or source of participants would necessarily influence the results, the possibility cannot be ruled out. Second, the instruction delivered in each treatment condition represented a specific instantiation of the ID model with which it was aligned. Other variations developed to train practitioners to perform CVC’s could vary in small ways that could influence their effectiveness. A third limitation is the study’s sample size. Replication using larger samples would provide greater statistical power to detect significant differences. Fourth, participants were novices in performing CVCs. Learners with more task expertise might not have responded equivalently to the instructional approaches used.30

**Conclusions**

The findings of this study are applicable to several important issues in medical training. First, they highlight the importance of ID beyond the influence of content and technologies used to deliver that content. In this case, both training models delivered identical information about how to perform a CVC procedure and used the same simulator. The differences observed in postinstruction performance clearly reflect the influence that selection of ID model can have on training efficacy. Second, the fact that GEL surfaced as the more effective ID model in this comparison demonstrates the value of highly explicit instruction and expert demonstration before task performance as an effective strategy for training health care providers unfamiliar with the procedure. This conclusion bears particular relevance for simulation-based instruction, which often uses an ELT instructional model,10 providing evidence that alternative models could result in safer and more effective performance of medical treatment procedures.

**References**

## Appendix

### Evaluation checklist

| Participant name: __________________________________________________ | Date: _________________________ Condition: 1 2 |
| Did the participant: (0 = no, 1 = yes) | 0 1 |
| Select the most appropriate site | 0 1 |
| Prepare the skin widely around the insertion site and isolate the site by sterile dressings | 0 1 |
| Glove and gown | 0 1 |
| Identify the proper landmark(s) | 0 1 |
| Inject patient with 1% lidocaine | 0 1 |
| Insert the needle at the correct angle to the skin | 0 1 |
| Aspirate constantly while inserting the needle | 0 1 |
| Occlude the needle hub to prevent air embolism | 0 1 |
| Feed the guidewire through the needle to the appropriate depth | 0 1 |
| Withdraw the needle and incise the skin | 0 1 |
| Insert and remove dilator device | 0 1 |
| Insert the catheter and withdraw the guidewire | 0 1 |
| Aspirate blood and flush all ports | 0 1 |
| Secure the catheter by suturing to the skin | 0 1 |
| Seal the whole site in sterile fashion | 0 1 |
| Total score _________ |  |
| Circle one → | PASS | FAIL |
| Critical actions resulting in immediate failure |  |
| 1. Improper sterility (before and after insertion) |  |
| 2. Letting go of the guidewire |  |
| Time the participant began/finished the study: __________/__________ Total time: |  |
| Time participant began/finished practice: __________/__________ Total time: |  |
| Time the participant began/finished the evaluation: __________/__________ Total time: |  |