“Simulation-based bronchoscopy training: randomised trial comparing worked example to video introduction”

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Abstract

Learning the complex skill of bronchoscopy involves the integration of cognitive domains and motor skills. The development of simulators has opened up new possibilities in bronchoscopy training. This study aimed at evaluating how effective the modelling example methodology is in training this skill and assessed its effect on cognitive load in learning. **Methods:** Forty-seven medical students participating in a simulator-based bronchoscopy training program were randomly allocated to a control group, receiving a video lesson, and the modelling example group. They were evaluated by the simulator’s metrics at different time points: pre-test, post-test and 15 days and 12 months after training. Cognitive load was assessed with the modified Paas scale. **Results:** Simulation-based training was effective for both groups, based on simulator metrics (p<0.05). The modelling example group outperformed the control group in all measures at post-test and after 15 days (p<0.001). After 12 months, there was a decline in skill in both groups, but the modelling example group performed better (p<0.001). Simulation-based training reduced cognitive load, more strongly so in the modelling example group (p<0.001). **Conclusion:** The modelling example group showed substantial benefits over the control group, both in reducing the cognitive load in learning and in retaining knowledge and skill after 15 days and 12 months.
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Results: Simulation-based training was effective for both groups, based on simulator metrics (p < 0.05). The modelling example group outperformed the control group in all measures at post-test and after 15 days (p < 0.001). After 12 months, there was a decline in skill in both groups, but the modelling example group performed better (p < 0.001). Simulation-based training reduced cognitive load, more strongly so in the modelling example group (p < 0.001).

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INTRODUCTION

Performing bronchoscopy comprises a knowledge of airways anatomy, cognitive domains like memory and attention, and skills such as dexterity and coordination. In the traditional teaching method (“see one, do one, teach one”), apprentices perform the procedure directly on the patient under the supervision of experienced professionals. Although this method is commonly regarded as safe, there is a risk of complications, especially in the early stages of learning, due to the apprentice’s inexperience and stress.

The emergence of simulators has revolutionized medical skills education. Simulation can offer structure to training and exposure to rare events in a risk-free and low-stress environment. The first bronchoscopy simulations used animal models. Technological developments gave rise to high-fidelity virtual reality simulators that detect the operator’s movements, simulate respiratory incursions, and provide feedback at the end of the procedure. Their use has provided gains, such as less time to perform the exam and more dexterity, in the early stages of training novice bronchoscopists, i.e., residents, to learn this skill in a virtual environment and on real patients. At present, simulators are not widely used in the training of medical students, although their use might benefit students by providing opportunities for a better understanding of anatomy and sparking interest in this area.

Because the purchase and use of the bronchoscopy simulator equipment is expensive, effective training methods are needed. Learning complex skills, like bronchoscopy, is not only dependent on the teaching process, but also on the mental effort that such learning requires. According to cognitive load theory, there is a connection between limited working memory capacity and unlimited long-term memory. For adequate learning, especially for beginners, cognitive loads should be managed properly to help reduce the ineffective extrinsic load by improving the intrinsic load (inherent to the task), and by freeing up working memory space to optimize the relevant load and consequently form mental schemata, that allows the consolidation and automation of knowledge.

The worked example method was developed as an instructional method to optimize the balance between relevant cognitive load and ineffective extrinsic load. It comprises a written example of a problem and a solution. One of its formats, known as the modelling example, occurs through observational models, which can be human or animated models demonstrated to the learner by video or in person. The modelling example involves presenting a didactic solution to executing tasks, and is appropriate during the early phases of learning and in activities with high interactivity.

Written worked examples have been shown to be applicable and useful in learning clinical reasoning. The modeling example format has been shown to be effective in clinical skills such as diagnostic performance and communicating bad news. The simulation of surgical techniques was effective in suturing, knot tying,
and robotic surgery. Similarly, integrating a virtual simulator into a bronchoscopy training program was associated with improved bronchoscopy skill and performance.

However, whether or not the application of the modelling example methodology in teaching bronchoscopy through simulators has an impact on the learners' cognitive load during training and on their long-term knowledge and skills mastery retention is unknown.

Thus, this study aimed to evaluate the effects of the worked example teaching method, in its in-person modelling example format, in simulation-based bronchoscopy training, on long-term knowledge retention in this skill, and on the learners' cognitive load during the learning process.

MATERIALS AND METHODS

Study Design

We conducted a randomized controlled trial to assess the in-person modelling example in learning bronchoscopy through simulation in the short (immediate test), medium (after 15 days), and long term (after 12 months) and to investigate its effect on cognitive load.

Participants

Sixty third-year medical students from the Federal University of Minas Gerais (Universidade Federal de Minas Gerais - UFMG) were recruited to participate in the study, which was conducted in the University’s simulations laboratory in September, October, and November 2019 and again in November and December 2020. All students had been taught knowledge of the respiratory tract anatomy. Students who had already had contact with bronchoscopy were excluded.

Simulator Used

We used the AccuTouch Flexible Bronchoscopy Simulator® (Immersion Medical Systems, Gaithersburg, MD, USA), a device with a flexible bronchoscopic shaft that can be introduced by the operator through the nose of a model of the human face. The system software records the operator’s movements and simulates the presence of endobronchial secretion and respiratory movements. During the exam, vital data are shown on the monitor. At the end, the device offers feedback on a number of validated simulator’s metrics: bronchoscopy execution time, number of collisions to the bronchial wall, red-out time, and percentage of bronchi examined.

Study Protocol

Participants were randomized by electronic random number generator into a control group receiving a video lesson and an intervention group receiving the modelling example. All participants completed the WMT-2 test to assess intelligence and the attention span (d-2R) test comprising performance measures for concentration, target objects processed, and percentage of errors at baseline. They also answered a questionnaire about previous hours spent on video games at baseline.

Figure 1 shows the study protocol. The bronchoscopy course included an introductory class followed by simulation training with previously selected cases, performed individually. An atlas of airway anatomy on paper was given to participants and was available throughout the training. The participants attended a video lesson (control group) or face-to-face class (modelling example group) during 20 minutes containing a brief review of the pulmonary anatomy and bronchial segments, use and applicability of bronchoscopy and didactic sequences, showing the movement of the hands during the exam.

During training, participants performed three simulated cases, and each case was repeated twice. The simulator’s road signs mode, showing the name of each examined bronchus, was used in the first round of each case. In the modelling example group, before the student performed the bronchoscopy, the instructor executed the examination while the student watched. To direct the student’s attention to the essential parts of the examination, each case/example was demonstrated with verbal cues. In the first case, the instructor performed the bronchoscopy for five minutes and provided guidance for handling the device. The student’s
attention was directed to the anatomy in the second case, which was also five minutes, and the systematic stepwise performance of the bronchoscopy was indicated in the third case for three minutes.

The students had 15 minutes to perform each bronchoscopy but were instructed to perform their best bronchoscopy in the least amount of time possible. Once the exam was over, the simulator’s metrics were displayed on the monitor and presented to the student, followed by structured feedback on hand movements and posture during the exam.

The students were assessed from simulator metrics with a pre-test, post-test, retention test (after 15 days), and delayed test (after 12 months) in these validated variables: a) bronchoscopy execution time, b) number of collisions on the bronchial wall, c) red-out time, d) percentage of bronchi examined, e) percentage of bronchi examined/minute. We included the validated measure – percentage of bronchi examined/minute – because it reflects skill better than the other measures alone.

Participants completed the Paas scale to observe cognitive load referring to each evaluation phases. It is a one-dimensional scale of mental effort which includes a nine-point Likert scale, where one indicates the least mental effort and nine represents the most mental effort in learning a task.

Statistical Analysis

To make comparisons between the phases for each group and for each phase of the study, we used the Friedman and Mann-Whitney U tests, respectively considered statistically significant. To assess whether the group of 47 students who completed the one-year assessment was comparable to the initial population of 60 students, the Student’s t-test and Fisher’s Exact test were used.

Ethical Aspects

The institution’s Research Ethics Committee approved the research project and consent form under no. 84057318.7.0000.5149.

RESULTS

Participants’ Characteristics

Of the 60 students included in the study, 47 (78%) returned for follow-up after one year. Thus, our results are based on these 47 students: 25 in the control group and 22 in the modelling example group. This group was comparable to the initial population of 60 students with respect to gender (p=0.215), age (p=0.838), video game hours (p=0.781), CP (p=0.597), TOP (p=0.968), E% (p=0.638) and WMT-2 (p=0.534).

Table 1 shows the distribution of all baseline variables between the two study groups.

Simulator’s Metrics

Table 2 presents the results of the bronchoscopy performance, based on the simulator’s metrics. The groups presented similar results in the pre-test, except for the number of bronchi examined (p=0.006) and bronchi examined/minute (p=0.011). Both groups showed significant improvement between the pre- and post-tests for all variables (p<0.05). However, the modelling example group performed better than the control group in all variables.

The retention test was taken after 15 days, and both groups exhibited results similar to the post-test results (p>0.05), except for bronchi examined (p<0.001) and bronchi examined/minute (p<0.001) in the control group and bronchi examined/minute (p<0.001) in the modelling example group, the results of which were lower than the post-test results. Nevertheless, these results were higher than the pre-test results for both groups. The modelling example group also performed better than the control group in this phase.

In our evaluation of long-term knowledge retention after 12 months, we observed a decline in skill in both groups for all variables, which were similar to the pre-test results, except for time in the modelling example group, which was lower than the pre-test value (p<0.001), and collisions and red-out in the control group,
which were higher (p<0.001) than the pre-test values. A comparison of the groups in this phase again showed that the modelling example group was statistically superior to the control group.

**Cognitive Load**

Table 3 illustrates the results for cognitive load. We found no significant difference in cognitive load between the two groups in the pre-test. After training, there was a significant reduction in cognitive load for both control group (p<0.001). However, the modeling example group exhibited a significantly lower cognitive load than the control group. Both groups demonstrated higher values in the retention test than in the post-test (p<0.001), but the modeling example group presented significantly lower values than the control group. After one year without training, the control group's values were similar to those in the pre-test, while the intervention group's values were significantly lower than those in the pre-test (p<0.001).

**DISCUSSION**

In this study, we aimed at assessing the impact of the in-person format of the modelling example methodology on simulation-based bronchoscopy training in the short, medium, and long term and its effect on cognitive load for medical students. Its application led to better performance in the intervention group than in the control group in the three evaluation phases of the study, and it reduced cognitive load during learning.

In this study, bronchoscopy training through simulation was effective as the participants' performance based on simulator metrics improved, thus indicating the importance of simulation-based training. Similar results were found in self-training programs with physicians in training, whose dexterity (p=0.022) and anatomical accuracy (p=0.029) improved\(^{23}\). Another study identified a higher percentage of bronchi examined (p=0.04) and a reduction in the number of collisions on the mucosa (p=0.024) among physicians in training, whose results were comparable to those of experienced bronchoscopists\(^{24}\). Self-training through bronchoscopy simulators was also effective with medical students. Veaudor et al. observed a reduction in execution time for the procedure and better performance (p=0.002)\(^{25}\). Gopal et al. noted that students' performance improved with higher scores on the Bronchoscopy Skills and Tasks Assessment Tool (BSTAT) (p<0.0001)\(^{26}\).

The present study shows that applying the modeling example methodology led to superior performance in all phases and helped improve learning. These findings are similar to those presented by Bjerrum et al., who also evaluated the in-person modeling example in simulation-based bronchoscopy training for students and found that the modeling example group presented significantly better results than the control group (p<0.0001)\(^{19}\). Another study showed that the peer modeling example among students is also effective in simulation-based bronchoscopy training as performance improved (p<0.001), similar to the control group (p<0.16), and it concluded that peer training in pairs is more effective since the same instructor and training resources can be employed\(^{20}\).

In contrast to our findings, Schertel et al. did not identify a difference between tutor-assisted bronchoscopy training with a simulator and self-training by students. Both groups improved significantly in their knowledge of anatomy. However, when the authors analyzed the effect size, the tutor-assisted group exhibited greater gains in skill between the pre- and post-tests with mean effect sizes between 0.46 and 0.6327, thus revealing the importance of observation in learning this skill.

Since we are addressing training in a complex skill such as bronchoscopy, we thought it was relevant to investigate learning in the short, medium, and long term. Furthermore, due to unprecedented circumstances such as COVID-19, it has become even more crucial to evaluate the clinical applicability of learning bronchoscopy through simulators. The training of human resources in this procedure should be continuous, without interruptions such as those imposed by the pandemic. In this study, we found that the modeling example resulted in better performance of the skills after training and better knowledge retention in the medium term, after 15 days. Nonetheless, we detected a significant decline in skill in the long term, although the modeling example still had better results than the control group.

A decline in skill with bronchoscopic intubation\(^{28}\) and pulmonary isolation in anesthesia training\(^{29}\) has been observed after two months without training. With other skills, such as interventional radiology, surgery, and
pediatric resuscitation, a significant decline has also been observed after six months without training\(^{30,31}\).

However, this decline in skill in simulation-based bronchoscopy training had not been observed before, thus highlighting our study’s originality.

In this context, medical education based on CLT has been applied. The construction of mental schemata allows for the allocation of cognitive loads and space in working memory and thus consolidates learning\(^9\). It is important to measure cognitive load so as to assess the effectiveness of the instructional method. In this study, managing the intrinsic load through the modeling example led to better performance in bronchoscopy and was associated with less mental effort, as established by CLT.

Managing the intrinsic load by dividing simulation-based training in surgical skills into several sessions, instead of a single day of training, also proved effective and reduced cognitive load and improved learning\(^{32}\). The mechanism for this phenomenon is the formation of mental schemata, which carry potential implications in the training curricula of surgical skills.

However, an increased cognitive load is associated with worse performance. In our study, participants in the control group demonstrated a higher cognitive load and a lower level of performance in bronchoscopy. Similar results were reported for the training of other complex skills with a simulator, such as laparoscopy and surgical knot tying: higher workload scores were associated with worse performance\(^{33,34}\). The ability to maintain a good level of performance with a low cognitive load is considered an important marker of expertise and learning.

In this context, it is essential to distinguish learners who actually retain knowledge from those who only maintain a good level of performance at the expense of great mental effort. This reinforces the importance of the cognitive load scale in our study, a precursor of this evaluation in bronchoscopy simulation.

Another relevant point in our research was the structured feedback. Although the simulator provides its own metrics, it does not contemplate posture and hand movements. Therefore, offering structured feedback was essential and reinforced the control conditions. The importance of this strategy was evident in simulation-based training in colonoscopy and robotic surgery, whose participants’ performance improved significantly\(^{35,36}\).

Another strict control condition in our investigation was the application of the WMT-2 and d2-R tests. We applied these tests since bronchoscopy requires the simultaneous coordination of several cognitive domains, as well as to ensure that the groups were comparable. Consequently, we were able to assess the instructional method concretely. Moreover, our data collection protocol was carefully designed and took place in a quiet environment, thereby minimizing the extraneous load.

This study presents some limitations. We used only the simulator’s metrics to evaluate the learners, not structured methods such as the BSTAT. However, there is evidence that simulators’ metrics are able to discern the basic clinical skills of bronchoscopists\(^{23}\), which implies that they meet the objectives of our research. In addition, the amount of time and effort involved by the supervisor is highlighted, relating to the applicability and cost-effectiveness of the training.

Another issue refers to the application of a one-dimensional scale of mental effort instead of multi-dimensional scales, although recent studies have noted their correlation\(^{37}\). Multi-dimensional scales are extensive and require more time to fill out, which may impair the students’ performance. Future studies should include concepts of metacognition to assess cognitive load\(^{38}\). Furthermore, it would be interesting to determine whether skills learned in simulation are transferable to real patients.

**CONCLUSION**

The results of our study suggest that simulation-based bronchoscopy training is effective as the learners’ performance improved. By applying CLT through the modeling example, we noted substantial gains associated with a reduction in cognitive load for learning. With the use of this resource, knowledge was retained in the short and medium term, and there was a decline in skill after 12 months without training. Nevertheless,
the modeling example group exhibited better results than the control group. This finding highlights the importance of modeling in bronchoscopy training. Further research is needed to examine cognitive load with multi-dimensional scales, in addition to other scales that evaluate the appropriation and mastery of skills acquired through simulators and the subsequent performance of learners on real patients.

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