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Do One *Then* See One: Sequencing Discovery Learning and Direct Instruction for Simulation-Based Technical Skills Training

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Abstract

Purpose
When teaching technical skills, educators often include a mix of learner self-regulation and direct instruction. Appropriate sequencing of these activities—such as allowing learners a period of discovery learning prior to direct instruction—has been shown in other domains to improve transfer of learning. This study compared the efficacy of learners trying a novel simulated suturing task before formal instruction (Do then See) versus the more typical sequence of formal instruction, followed by practice (See then Do) on skill acquisition, retention, and transfer.

Method
In 2015, first-year medical students (N = 36) were randomized into two groups to learn horizontal mattress suturing. The See then Do group had access to instructors before independent practice, whereas the Do then See group explored the task independently before accessing instructors. Participants were assessed at the transition between interventions, and as training ended. Skill retention, and transfer to a novel variation of the suturing task, were assessed after one week. Performance was scored on a five-point global rating scale by a blinded rater.

Results
The groups did not differ significantly on immediate posttest or retention test ($F[1,30] = 0.96$, $P < 0.33$). The Do then See group (N = 16) outperformed the See then Do group (N = 16) on the transfer test; 2.99 versus 2.52 ($F[1,28] = 10.14$, $P < 0.004$, $\eta^2 = 0.27$).

Conclusions
Sequencing discovery learning before direct instruction appeared to improve transfer performance in simulation-based skills training. Implications for future research and curricular design are discussed.

Encouraging learners to direct their own learning has been an active area of investigation for medical educators. Most agree that "activating" learners can enhance traditional education: Self-regulated learning (SRL) can be efficient,[1] diagnostic,[2] and effective[3,4]—but the extent of learner involvement and control, as well as whether and how to integrate SRL with instructor-led sessions, remains understudied. Indeed, a recent systematic review and meta-analysis of simulation-based training showed that researchers compare SRL and instructor-led interventions often, yet few study how to combine the two approaches.[3] During a typical session in any medical curriculum, educators may combine direct instruction and learner-driven SRL, likely in an idiosyncratic fashion. Further, at the curricular level, most medical schools now include periods of assigned SRL, without clear guidelines for how to integrate those periods with sessions involving direct instruction. Researchers in educational psychology suggest that the best learning outcomes may arise when educators thoughtfully and meaningfully integrate SRL and direct instruction,[5,6] yet medical educators have little evidence to draw on when determining how to combine the two. Optimizing their combination has the potential to optimize learning.

Traditional teaching usually involves direct instruction: A teacher or instructor first deconstructs the topic or skill of interest, explains the essential concepts, and demonstrates the application. Direct instruction usually precedes time when students later attempt to solve problems with the teacher's guidance and feedback. People find this sequence of teaching so intuitive that they hardly pause to question its effectiveness. There is a vast amount of literature attesting to the benefits of direct instruction,[7–9] particularly for faster and more accurate performance. However, optimizing immediate performance does not always guarantee future transfer of learning or retention,[6] which are valuable when considering the range of similar but nonidentical tasks that trainees will eventually experience in the workplace.

By contrast, discovery learning involves trainees receiving minimal guidance, allowing them to explore the learning task and to experiment with different solutions to a problem; variations include inquiry-based learning and problem-based learning.[10] In these models, students autonomously address the learning task and construct their own meanings, as opposed to having them imposed by an instructor. Proponents of discovery learning argue that it enhances transfer of learning and learner self-regulation and is a more learner-centric approach.[11,12] Advocates of direct instruction counter that discovery learning induces unnecessary cognitive load, results in inaccurate or weak mental

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representations of content, and poses undue stress on trainees.[13] Indeed, head-to-head comparisons of direct instruction versus pure discovery learning have typically found that pure discovery is a weaker form of instruction.[13]

Contemporary research in education has moved beyond an "either–or" approach, focusing instead on the optimal sequencing of direct instruction and discovery learning.[6] The specific sequence of discovery learning prior to direct instruction, known as *guided discovery*, has been studied, for example, in statistics instruction, where students solved problems on the concept of standard deviation.[14] Crucially, the problems required students to examine some data and develop their own approaches to measuring consistency. After this initial discovery phase, instructors then formally explained standard deviation and its applications. Alternatively, a comparison group attended a traditional lecture followed by SRL of practice problems. The primary outcome included students' knowledge of standard deviation, and also how well they applied their knowledge to novel, related transfer tasks.[15,16] On transfer, the guided discovery group far outperformed the traditional training group. Similar studies have been conducted in concept learning, with consistent findings for transfer of learning[17–19]; notably, these studies often show little benefit of guided discovery on retention. Focusing on assessing retention performance may obscure the benefits of guided discovery, which tests of transfer may make visible.[20] Even some dedicated proponents of direct instruction acknowledge the utility of guided discovery[8] when training for transfer.

Most studies of guided discovery[14–19] have focused on concept learning, with research only now emerging in skills training in medical education.[20] Thoughtful incorporation of guided discovery into training modalities such as simulation-based training may optimize transfer to the clinical setting. Guided discovery may have other benefits, such as using limited instructor time with learners more efficiently. It may also help learners calibrate their self-efficacy and actual skill level.[1] In the present study, we experimentally tested the efficacy of two sequences of discovery learning and direct instruction on the acquisition, retention, and transfer of simulated suturing skills in undergraduate students. We hypothesized that the sequence of discovery, followed by direct instruction, would benefit students' transfer of skills, but not their retention or immediate posttest performance. We also examined how the two sequences impacted students' perceived self-efficacy and competence.

Method

Our experimental study compared two forms of training for suturing skills at the University of Toronto Surgical Skills Centre at Mt. Sinai Hospital. Participants were randomized to learn suturing skills on a skin-pad simulator through (i) direct instruction followed by discovery learning (See then Do), or (ii) discovery learning followed by direct instruction (Do then See).

Population

We recruited first- and second-year undergraduate MD students (N = 32) at the University of Toronto, who were naïve to the suturing tasks and thus, we expected, could be influenced by both forms of instruction. We based our sample size on an expected moderate effect size, and in keeping with previous research using our primary outcome.[1] Participants completed two study sessions one week apart in which session 1 involved delivery of the interventions and immediate posttest and session 2 involving retention and transfer testing. Two cycles of the study took place, one in April and one in November 2015.

Ethics

We received ethics approval for recruitment and data collection from the University of Toronto Health Sciences Research Ethics Board.

Materials and tasks

For both practice and all testing, participants used custom-made silicone simulated skin pads and a standardized suturing kit (Faux Medical Corporation). We assigned the horizontal mattress suturing task, using Ethilon nylon monofilament suture, because we expected that it would be challenging for participants but could be taught and assessed relatively efficiently. For the transfer test, we placed the same skin pads in an abdominal cavity simulator.

Procedures

After consent and randomization, participants completed a short survey estimating previous time spent on (a) any suturing, (b) horizontal mattress suturing, and (c) knot tying. After this, the research assistant introduced them to the relevant procedures for their respective groups. All participants completed an initial session in their assigned group, working in small groups of six to eight. That session included two performance assessments. After a one-week delay, participants returned to complete a retention test and a transfer test. Performances on all tests were scored by a single rater blinded to participants' group assignment.

Interventions and design

In the See then Do group, participants first learned with instructors, who demonstrated and explained the steps in completing the suturing task twice. The instructors also allowed participants to practice independently, and provided individualized feedback as requested in a semistructured environment. Participants were encouraged to ask questions and solicit feedback. We aimed for a 1:3 instructor ratio during this phase. Instructors were junior- and senior-level residents in the orthopedic surgery postgraduate residency program, all with basic technical skill teaching experience. In an effort to standardize instruction, we gave instructors a teaching script (see Appendix 1). Although this limited the ability of instructors to initially adapt their instruction to their participants, it provided a measure of control for our comparison with the Do then See group. After 30 minutes of instruction, participants completed a self-efficacy rating and performed a horizontal mattress suture (midpoint test), without any instructor feedback. Participants then had 30 minutes to practice on their own in small groups, without instructors. The full session ended with participants completing the self-efficacy rating and performing a horizontal mattress suture (immediate posttest), without any instructor feedback.

The Do then See group had the sequence of training inverted, with a discovery phase prior to contact with instructors. For the first 30 minutes, participants received the skin pads, suturing material and equipment, and an example diagram of a completed horizontal mattress suture. The RA encouraged participants to use the diagram as a guide as they attempted the horizontal mattress suture. Participants did not receive any guidance, feedback, or further instructions. We asked participants to complete the task alone, with minimal interactions with each other. After 30 minutes, participants completed the midpoint test of suturing performance and a rating of their self-efficacy. Next, the participants worked directly with instructors, who demonstrated, and provided feedback in a 1:3 instructor-to-participant ratio for 30 minutes. The session ended when participants completed the immediate posttest of their self-efficacy and suturing performance.

After a one-week delay, participants completed a retention test, consisting of two horizontal mattress sutures on the same skin pad on a table top. Immediately following that test, they also completed a transfer test consisting of two horizontal mattress sutures on the skin pad placed in an abdominal cavity simulator, using elongated instruments and the same suturing materials. All participants completed self-efficacy questionnaires prior to both retention and transfer tests.

Outcomes

Our primary outcome was performance on the delayed "near-transfer" test. We categorized the test as near-transfer because the fundamentals of horizontal mattress suturing had not changed, though important contextual task elements were altered, requiring participants to perform the same motor skills with moderate variations in instrument handling and motor skills requirements.

Our secondary outcomes were performance on the midpoint, immediate post, and retention tests. We also collected data on participants' self-efficacy, using a visual analogue scale of 0 to 100 which asked participants to judge themselves according to a previously studied scale[21]: "On a scale from 0 to 100 with 10 being not sure, 40 being somewhat sure, 70 being pretty sure, and 100 being very sure, how sure are you that you will perform your next suturing and knot-tying attempt effectively and safely?"

Scoring

A single blinded rater scored participants' performance using the global rating scale (GRS) from the Objective Structured Assessment of Technical Skills system, for which there is considerable and strong validity evidence for assessing performance of novice learners in a research setting.[22] The GRS consists of six items evaluating elements of the procedural skill, and one overall process item; all items are on a five-point Likert scale, with verbal anchors at 1, 3, and 5 (see Appendix 2), and a higher score indicates superior performance. The GRS score used in our analyses is an average across all items.

Analysis

Analysis of transfer performance was through analysis of covariance (ANCOVA) with intervention as the between-subjects factor and retention performance as the covariate. We included participants' retention score as a covariate to gauge the effect of individual variation in suturing skill, and because other studies using transfer as the primary outcome often do not include a test prior to their transfer test; hence, we included the retention test score as a covariate to account for likely interdependence between performances on the two tests. We included other covariates, such as previous hours of experience, and previous suturing attempts, only if they were shown to predict transfer performance. We analyzed participants' scores on the other tests (midpoint, immediate post, and retention) using a repeated-measures ANOVA (group × test). For the self-efficacy scores, we analyzed using another repeated-measures ANOVA, across all four tests (midpoint, immediate post, retention, and transfer). We set significance at an alpha of 5% two sided, and applied the Bonferroni correction when conducting multiple comparisons. Analysis software was done with SPSS 22 (IBM Corporation, Armonk, New York).

Table 1
Experience of Participants With Suturing and Knot Tying, Shown in Hours

	Do then See, median (SD)	See then Do, median (SD)
Experience with any suture	2 (1.01)	2 (0.99)
Experience with horizontal sutures	1 (0.78)	1 (0.39)
Experience with knot tying	1 (1.18)	1 (0.79)

Results

We recruited 18 participants per study arm, and 2 from each group dropped out during the delay period; thus, we analyzed 16 participants per group. The majority of participants had less than one hour of experience with each task (see Table 1). Participants' self-reported number of hours suturing correlated with their transfer performance at $r = 0.49$ ($P < .005$) and, thus, was included as a covariate in the analysis of transfer test performance.

Performance on the transfer task is presented in Figure 1. The ANCOVA showed that the Do then See group outperformed the See then Do group on the transfer task at 2.99 (SE = 0.10; 95% CI: 2.78–3.20) compared with 2.52 (SE = 0.10; 95% CI: 2.31–2.73) ($F[1,28] = 10.14$, $P < .004$, $\eta^2 = 0.27$). There was no significant interaction between participants' self-reported number of hours suturing and their group assignment ($F[1,28] = 1.12$, $P < .9$).

The repeated-measures ANOVA of suturing performance showed a significant effect of test ($F[2,60] = 18.01$, $P < .001$, $\eta^2 = 0.38$) and significant interaction between group and time ($F[2,60] = 5.23$, $P < .008$, $\eta^2=0.15$) (see Figure 2). The interaction was driven by the Do then See group's poor performance on the midpoint test, and the absence of a statistically significant group effect on immediate post and retention tests. Both groups improved from midpoint to immediate posttest ($P < .001$) and experienced a significant drop in performance on retention test ($P = .003$). We found no significant differences between groups overall ($F[1,30] = 0.96$, $P < .33$).

The ANOVA of self-efficacy across the four performance tests is reported in Figure 3. Data were missing for two additional participants in the Do then See group (N = 14), and one participant in the See then Do group (N = 15). We detected a significant main effect of test ($F[3,81] = 9.52$, $P < .0001$, $\eta^2=0.26$), where participants' self-efficacy was

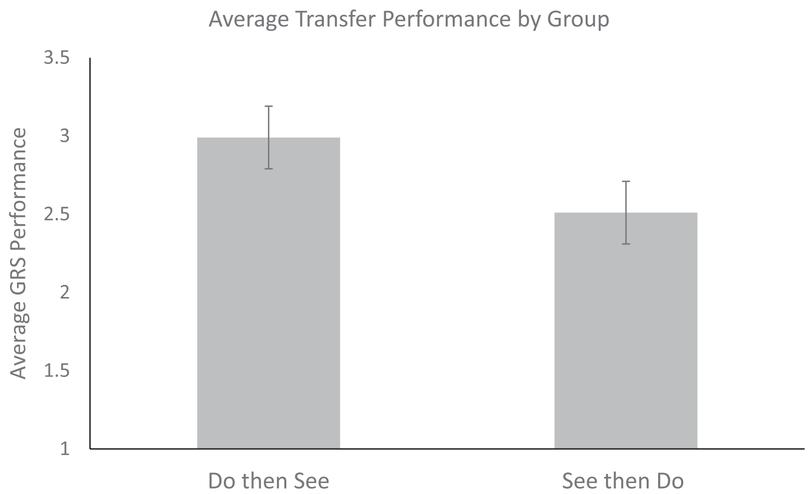

Figure 1 Performance on transfer suturing task by group; a significant effect for the Do then See group ($F[1,28] = 10.14$, $P < .004$, $\eta^2 = 0.27$).

low after the midpoint test, improved significantly at immediate posttest ($P < .001$), and declined significantly at retention ($P = .01$) and transfer tests ($P = .003$) for both groups. Overall, the See then Do group had significantly higher self-efficacy than the Do then See group for all tests ($F[1,27] = 8.5$, $P = .007$, $\eta^2 = 0.24$).

Discussion

We tested the impact of the usual apprenticeship model (See then Do) against guided discovery: a sequence of discovery followed by direct instruction (Do then See). We hypothesized that allowing learners to experiment with a task before interacting with an instructor would benefit their near-transfer test performance and would have no benefit for immediate posttest or retention test performance. Our findings confirmed those hypotheses. Crucially, learners in the Do then See group had lower self-efficacy than the See then Do group, despite having similar or statistically superior performance outcomes. Indeed, the group mean self-efficacy for the Do then See group never rose above the lowest group mean for the See then Do group. Our results align with evidence from concept and classroom learning, showing that the Do then See sequence enhances learning of simulated suturing skills and seemingly limits self-efficacy.

Discovery learning is not a novel concept for medical education, especially in preclinical training of fundamental concepts (e.g., problem-based learning, case-based learning). The ubiquity of simulation centers and the use of intensive "boot camps" for training technical skills[23] provide an ideal modality and curricular structure for using guided discovery approaches. Yet, the dominant training paradigm in simulation, mastery learning,[24] includes little time for discovery learning in any formal guidelines[25] and, instead, emphasizes direct instructor feedback and attainment of performance standards. Our results suggest that allotting some time to discovery learning may enhance transfer learning outcomes while also using less instructor time. Indeed, guided discovery curricula would use half the time required of faculty in a mastery-based course. Future studies might compare the Do then See sequence with a mastery learning model by evaluating learning, self-efficacy, and training efficiency (i.e., faculty time, use of consumable resources) as key outcomes.

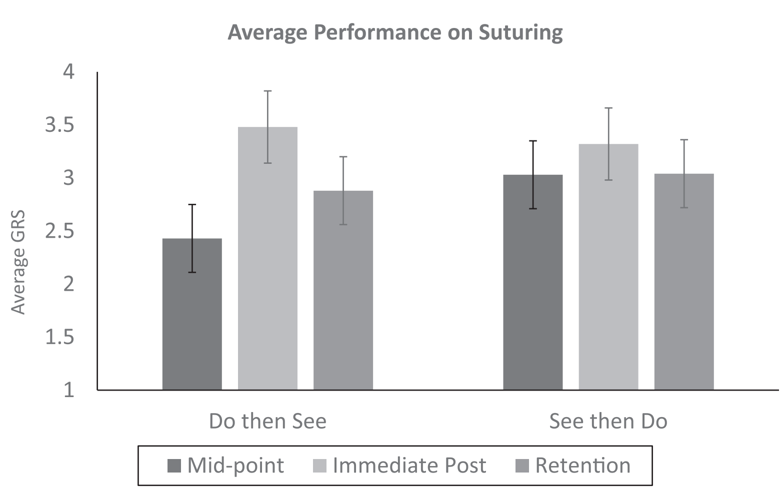

Figure 2 Performance on midpoint, immediate post, and retention tests. A significant effect of test ($F[2,60] = 18.01$, $P < .001$, $\eta^2 = 0.38$) and significant interaction between group and time ($F[2,60] = 5.23$, $P < .008$, $\eta^2 = 0.15$) but not of group ($F[1,30] = 0.96$, $P < .33$).

The See then Do group had higher overall self-efficacy across all tests, including the transfer test, despite having lower performance. Ample evidence demonstrates the perils of relying on learners' self-assessments[26,27] and self-efficacy to gauge competence. Our results further add to this phenomenon by showing that increasing learners' perceived fluency for a task might not align with actual learning.[28] This occurred with the See then Do group, which likely used their higher immediate performance (on the midpoint test) to judge the extent of their learning,[29] despite the retention and transfer test data showing that their higher self-efficacy was not warranted. This pattern is consistent with research showing that learning conditions that lead to increased immediate performance (i.e., our midpoint and posttests) often yield increased judgments of learning and, paradoxically, decreased future performance.[30] Conversely, the Do then See group may have had low self-efficacy because they experienced the "desirable difficulty" effect of struggling prior to being shown "how to do" the task. While inappropriate as a stand-alone measure, we suggest that self-efficacy is an imperfect metric for evaluating learning interventions, in addition to measuring learners' actual performance.

Previous studies provide many potential reasons why the Do then See sequence appears to improve transfer outcomes. First, a discovery period essentially forces

Figure 3 Self-efficacy across the four performance tests. We found a main effect of test ($F[3,81] = 9.52$, $P < .0001$, $\eta^2 = 0.26$), and the See then Do group had significantly higher self-efficacy than the Do then See group for all tests ($F[1,27] = 8.5$, $P = .007$, $\eta^2 = 0.24$).

learners to experiment with, and thus produce, a number of possible variations in how to perform the assigned task successfully.[17,18] Alternatively, direct instruction often exposes trainees to "the way to do it," and they may then work on replicating the routine variation they have just observed, rather than experimenting with different variations. There is evidence that variation during learning yields improved acquisition and subsequent transfer of performance.[31] This form of task variation is often characterized as "contextual interference" and may be afforded by the discovery phase.[32] In combination with direct instruction, learners may experience the necessary variation for successful transfer. Second, a degree of struggle when first learning a task may help learners take better advantage of subsequent time with the instructor, including asking more relevant or targeted questions[19] as well as attending to critical features of the movement. Our research assistants, participants, and instructors noted differences in their interactions, depending on the sequence of learning, though these anecdotes must be confirmed through rigorous, prospective data collection of behavioral measures. Third, a broader mechanism may also be found in the underlying rationale for constructivist education approaches including discovery learning. Constructivists stress the importance of allowing learners to construct their own "meaning" of the task by scaffolding it on their previous knowledge.[33] To do so successfully, learners must activate previous knowledge while engaging with the task; such activation prior to direct instruction may be an affordance of the discovery phase.[34,35] Clarifying which of these potential mechanisms is at play requires studies focusing on both behavioral measures and learning outcomes.

We must note some study limitations. Firstly, given logistical and funding challenges, we used a single blinded rater, which prevents us from producing a measure of interrater reliability. Fortunately, previous studies have shown that the intraclass correlation coefficient is typically acceptable when assessing suturing skills using the same GRS.[36] Secondly, our transfer task involved minimal change in the contextual elements from the original task, which we chose to illustrate the effect of our training sequences on higher-order learning outcomes, beyond strict replication and retention. We recommend, however, that future studies isolate retention and transfer outcomes separately, rather than including both tests in a single design. Alternative transfer outcomes studied in the concept learning literature include far transfer tasks where learners must innovate solutions or learn new ideas by using the concepts taught in the original session.[17] Thirdly, our study represents only one approach to integrating discovery and direct instruction. For feasibility reasons, we constrained the amount of time in discovery, the ratio of discovery to direct instruction, and the delay between discovery and direct instruction. Other forms of discovery learning, ratios between discovery learning and direct instruction, and time delay are surely worth exploring. Moreover, although our study had a randomized design, a relatively small sample size is still an issue because randomization may not balance the unknown confounders that may influence the effect. Future randomized studies should aim to replicate our effect with larger samples.[37] Lastly, we studied effects on learning outcomes alone, and encourage further study of the proposed mechanisms of these two learning sequences using behavioral and process measures.

Conclusions

Our study presents experimental evidence for the benefits of a Do then See sequence for transfer of learning in simulation-based surgical skills training. Allowing learners to experiment before they interact with an instructor may help balance learner autonomy and instructor time pressures. Moreover, our study shows that educators and curriculum developers will likely better serve learners by pausing to consider how to combine learner SRL and direct instruction within training sessions and across broader curriculum plans.

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Appendix 1

Instructor Template and Script

Suturing Instructor Script:

Today we will be learning the horizontal mattress suture.

Begin by selecting the 3-0 nylon suture. Open the package and grasp the needle of the suture with the suture driver. Position the needle so that it sits right at the tip of the needle driver and such that the needle driver grasps the needle 1/2 to 2/3 of the way from the sharp end to the blunt end of the needle. Sutures have "memory," meaning they will stay curled up and difficult to work with after removing them from the package. Pull gently on the suture material in a constant manner for a few seconds to reduce the coiling.

With the suture driver in your dominant hand, and the toothed Adson forceps in your nondominant hand, begin the procedure for the horizontal mattress suture. Start by elevating the skin gently on one side of the wound. Pronate your hand to position the needle 5 to 10 mm from the wound edge, and 90 degrees to the plane of the skin. Supinate your hand as you pierce the epidermal and dermal layers to curve the needle through and into the wound. Release your needle driver and regrasp the needle in the wound. Continue to supinate to bring the full needle through the skin. Next elevate the other side of the wound. Enter at the same depth (under the dermal layer) as you exited on the opposite side. Supinate aiming to have the needle exit the skin the same distance from the wound edge you entered on the opposite side. Release the needle driver and grasp the needle outside the skin. Continue to supinate to curve the needle completely out of the skin. Pull the suture through leaving a short tail.

At this point the suture needle must be loaded in the opposite direction, aiming back towards the original wound edge. You will enter the skin on the same side you just exited approximately 1 cm further down the wound edge. In a backhand fashion, pronate as you enter the skin at 90 degrees. Repeat the process of grasping the needle with wound and then after repositioning, complete the second bite on the original wound edge. Pull the suture through and prepare for an instrumented tie.

At this point the long tail of the suture should be farthest from you and the short end closer to you, both on the same side of the wound. Place your needle driver between the two tails. Loop the long tail around the needle driver end towards the short tail twice; this produces a surgeon's knot. Grasp the short tail with the needle driver and pull it through the loop, cross your hands as you pull the knot tight to lay it down flat. Place the needle driver back between the two tails. Again loop the long tail towards the short tail, which should now be on opposite sides than previous. Continue this process until at least four throws are completed.

Grasp the short tail in the suture driver when you have completed tying the knot. Pass the needle driver and long end of the suture into your nondominant hand. Grab the straight Mayo scissors in your dominant hand and cut both suture tails at least 1 cm in length.

Appendix 2

Wound Closure Global Rating Scale

University of Toronto
Department of Surgery
OSATS Global Rating Scale

UofT Department of Surgery

Wound Closure

GLOBAL RATING SCALE OF PERFORMANCE

Please circle the number corresponding to the candidate's performance regardless of the candidate's level of training.

	1	2	3	4	5
Respect for tissue	Frequently used unnecessary force on tissue or caused damage by inappropriate use of instruments		Careful handling of tissue but occasionally caused inadvertent damage		Consistently handled tissue with toothed forceps and caused minimal damage to tissue
Time and motion	Many unnecessary movements		Efficient time/motion but some unnecessary moves		Clear economy of movement and maximum efficiency
Instrument handling	Repeatedly made tentative or awkward moves with instruments didn't load needle correctly or follow curve of needle; did not handle needle safely		Competent use of instruments but occasionally appeared stiff or awkward		Fluid movements with instruments and followed curve of needle; needle protected at all times
Knowledge of Instruments	Frequently used inappropriate instrument; used Incorrect suture for the tissue layers		Familiar with instruments and used appropriate instrument		Obviously familiar with Instruments; used correct suture
Flow of Procedure	Frequently stopped operating and seemed unsure of next move		Demonstrated some forward planning with reasonable progression of procedure		Obviously planned course of operation with effortless flow from one move to the next
Knowledge of Specific Procedure	Deficient knowledge; required specific instruction at most steps of operation		Knew all important steps of operation		Demonstrated familiarity with all steps of the operation; correct knot tying technique with appropriate tension and square throws
OVERALL PERFORMANCE	Very poor		Competent		Clearly superior
QUALITY OF FINAL PRODUCT	Very poor; dog ears present; sutures engage more than one tissue layer; strangulation of tissue/failure to approximate wound edges		Competent; edges everted or opposed; sutures close wound effectively		Clearly superior; all knots to one side of wound, edges everted; sutures evenly spaced; equidistant bites

Examiner Sticker	Candidate Sticker