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RESEARCH ARTICLE

Surgical Learners Do Not Teach Skills According to How They Were Taught

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Abstract

Background: Surgeons are expected to teach students, residents and colleagues about surgical skills. The critical assumption that a "first-learner" will default to teaching a "second-learner" what they were taught, in the way they were taught, was investigated.

Methods: Thirty-six medical students without experience tying a locking, sliding knot were divided into 18 pairs of first- and second-learners. 4 pairs were assigned to the "traditional teaching" (T) protocol group, 5 pairs were assigned to the "operant-teaching" (O) group and 9 pairs were "informed of the importance of the operant teaching strategy" before instruction and assigned to the "operant-informed" (OI) group. First-learners were taught to tie the locking, sliding knot according to one teaching protocol (T, O, or OI). Successful first-learners were asked to teach a second-learner. For the first-learners, time from the start of their instruction to the first constructed knot, time to tie 10 consecutive knots, and accuracy of knots (number of incorrectly constructed knots) were recorded. For second-learners, time from start of instruction to the first constructed knot, time to tie 10 knots, and accuracy of knots were recorded.

Results: All first-learners, in all groups, were able to accurately tie a locking, sliding knot. During self-practice, all T-group first-learners lost the ability to tie the knot. Between the 5 O- and 9 OI- first-learners, only one OI-group first-learner lost the ability to tie the knot. After instruction from the 16 successful first-learners, 16 second-learners were able to tie to the knot. The error rate for second learners was 93% for the T-group, 20% in O-group and 12.5% in OI-group. Time to tie the first knot were different between the three teaching groups for both the first and second-learners ($p=0.007$ and $p=0.041$, respectively). The average time to tie the 10 knots was similar between first-learner ($p=0.336$) and second-learner O- and OI-groups ($p=0.788$).

Conclusion: Demonstration-based teaching results in incomplete skills which deteriorate. Contrary to the assumption that successful first-learners would teach the way they were taught, first-learners abandon the teaching strategy when tasked with teaching a second-learner. Our results emphasize the importance of incorporating teaching curriculums into surgical education.

INTRODUCTION

Background

Does see one, do one, teach one really work? All physicians are "first learners" in their career, and will eventually be tasked to teach another learner, a "second learner" who is a student, junior resident or a colleague. Although only few physicians receive formal training in adult education[1-3], they are expected to teach what they have learned as they progress in their medical training. This is of concern, as what they teach, how they teach and whether they achieve their teaching goal is of critical importance.

The key aspects of effective teaching in the medical setting include experience with surgeon-teacher role models, time to teach, and knowledge of the principles of adult learning and the associated teaching techniques[4-6]. Unfortunately, surgeon-teachers are increasingly left with less time for teaching due to time constraints resulting from both work-hour restrictions[7,8] and the growing emphasis on procedure volume[9,10]. Nowhere is this more apparent than in the operating room, where time pressures and ethical considerations make it difficult for surgeon-teachers to allow resident-learners the freedom to develop and transfer their operative skills. In addition, residents, who provide 20-70% of clinical teaching to junior residents and medical students[11], report that they had not received training in clinical teaching, report lack of proficiency and low to moderate comfort levels when teaching[12]. In response to these constraining forces, significant effort has been directed toward developing effective means to teach surgical skills based on the science of human learning[13-18]. Surgical skill laboratories have been implemented in many residency programs to teach simple surgical skills on low and high-fidelity models[15,17,19] with the way in which training is delivered becoming an important focal point. A previous study showed that simple surgical skills can be successfully taught using operant reinforcing methodology where complex skills are deconstructed into simpler tasks and achievement of a task is marked/reinforced using an acoustic, judgment-free marker [15]. Compared to traditional demonstration-based methodology, operant reinforcement resulted in more accurate, precise, and sound surgical skills in learners (first-learners).

Rationale

The critical assumption was that a learner who was taught via a structured methodology (operant reinforcement) would then default to teaching a second-learner via that same method. But was that assumption valid? It was unclear what would happen when a resident-learner (first-learner) became the teacher. What would be taught? What teaching method would be used? Would the second learner achieve the desired outcome?

The goal of this project was fourfold: 1.) determine whether a first-learner who was taught a simple surgical skill using operant reinforcement acquired and retained the skill (tying a locking, sliding knot) for a longer period of time than a demonstration alone taught first-learner, 2) determine whether a first learner can teach a second-learner the same skill with accuracy and precision, 3)

determine whether first-earners default to teaching in the manner in which they were taught and 4) whether informing first-learners as to the importance of specific teaching methods influenced the way they taught.

Materials and Methods

The study received IRB approval, exempt category 1. Thirty-six first- and second-year medical students volunteered for the study and were randomly divided into 18 pairs of first- and second-learners. None of the volunteers had prior experience tying a locking, sliding knot. Four pairs were assigned to a "traditional teaching" protocol group, 5 pairs were assigned to an "operant-teaching" protocol group, and 9 pairs were assigned to an "operant-informed" teaching protocol group (Figure 1).

Figure 1. Organization and Breakdown of Participants

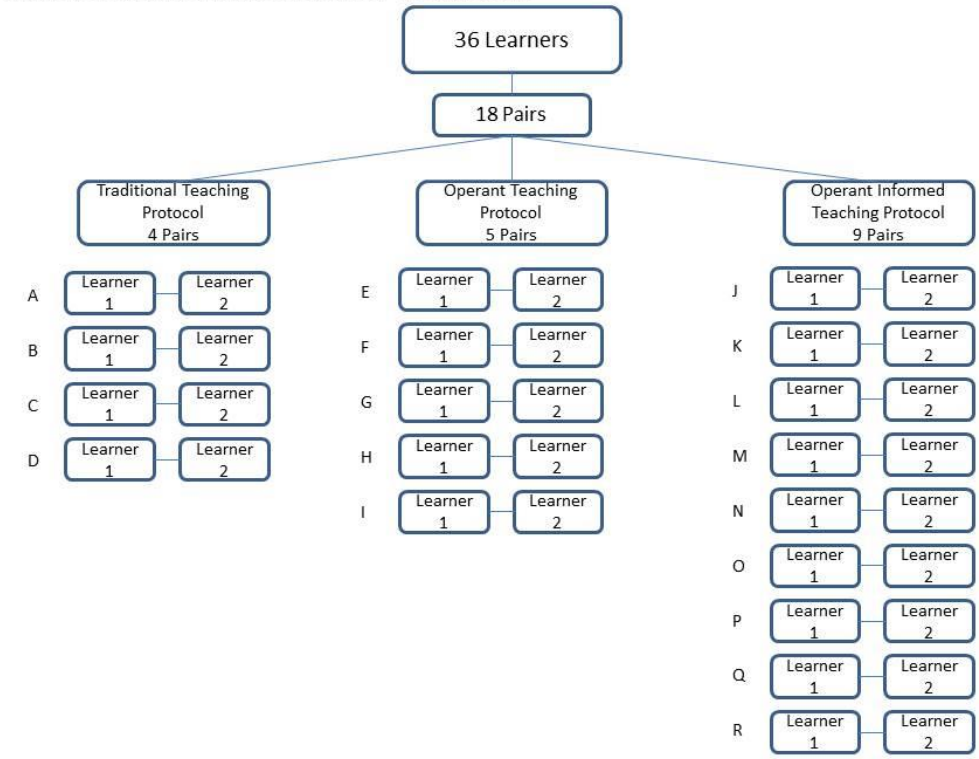

Figure 1: Participants and Learner Groups

The target skill was the tying of a locking, sliding knot (a Tennessee Slider variant; Figure 2) using a two-foot piece of one-fourth-inch braided nylon rope. The steps to tie the knot included: (1) place one-third of the rope directly over two-thirds of the rope; (2) wrap, then go over and through; (3) wrap to a fakey pinch (the rope coming from palm side to the thumb-index pinch; (4) maintain the loop; (5) go behind over and through; and (6) dress and slide the knot. Performance was considered successful only if all of the steps were performed accurately.

Teaching the first-learners and performance assessment of first-learners

First-learners were taught to tie the knot according to their teaching protocol.

In the traditional teaching (T) protocol group each first-learner saw two demonstrations with verbal descriptions of tying the locking, sliding knot. For consistency, a single instructor (the senior author) performed the demonstrations. Once the demonstrations were completed, the learner was given a single exploded diagram of the knot (Figure 2A) and they were then asked to tie a locking, sliding knot.

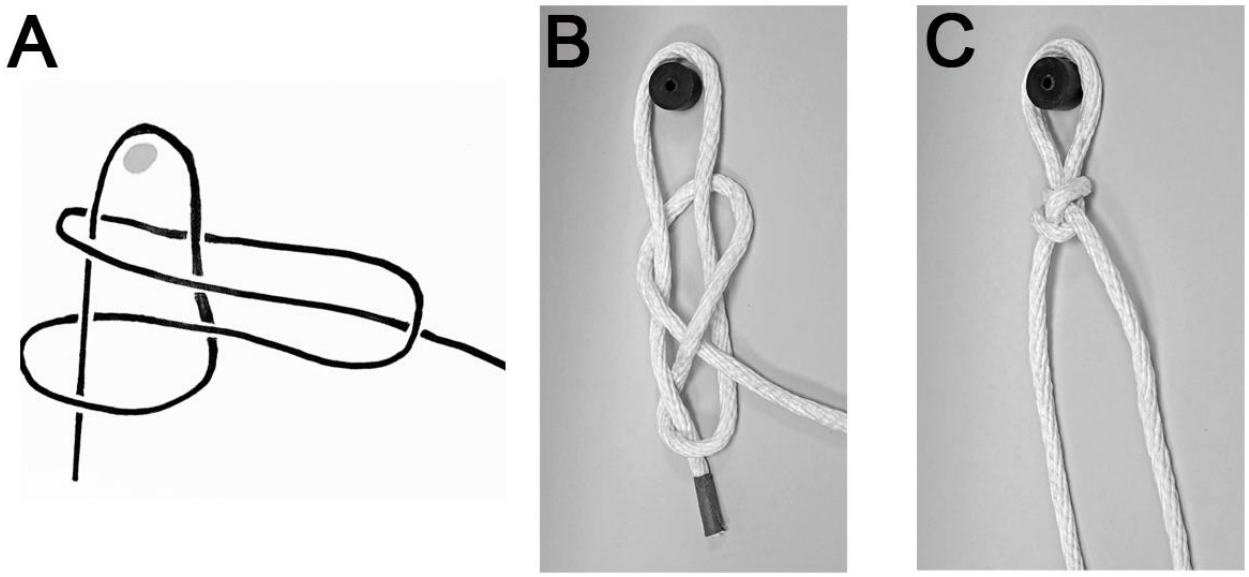

Figure 2: Locking, sliding knot

A, Exploded diagram of the locking, sliding knot as given to the traditional teaching group and B, actual image of it. C, Image of an accurately tied locking, sliding knot.

In the "operant" (O) protocol group, a single surgeon (the senior author), trained each first-learner to tie the locking, sliding knot using an operant methodology based on TAGteach, teaching with acoustic guidance, (TAGteach International, Indian Trail, NC, USA) and followed a precise script. First, the instructor identified the goal, "tie the locking, sliding knot". The instructor gave brief background information about the purpose of the knot which was followed by a single demonstration of tying the knot. Each person in this group then learned knot construction in 6 steps as described in Levy et al. [15]. In brief, the first step was identified, and instructions and a demonstration were given. The TAG point, that is, the aspect of the step to be marked with acoustic feedback (a click), was named using five words or less (Table 1). The learner was then asked to reproduce this step. A successful performance was marked with a click and the learner repeated this step five

times. Each of the 6 steps were learned in succession and then linked together until the learner successfully constructed the first locking, sliding knot.

Table 1. Instructions and "tag points" for creating a locking, sliding knot

Instructions and "tag points" for tying a locking, sliding knot
1) Instructions: Place 1/3 of the rope directly over 2/3 of the rope Tag point: 1/3 directly over 2/3
2) Instruction: Wrap, over and through Tag point: Through
3) Intructions: Wrap to a fakey pinch Tag point: Fakey pinch
4) Instructions: Flatten and maintain the loop Tag point: Maintain the loop
5) Instructions: Behind, over through to Backside grab Tag point: Backside grab
6) Instructions: Dress and deliver the knot Tag point: Deliver the knot

The "operant-informed" (OI) protocol group first-learners were taught using the teaching protocol for the operant-learners described above, except that at the conclusion of the background information and prior to the stepwise approach to teaching, they were specifically told the script, "the methods by which you are taught, matter".

For all three groups, time to construct the first knot correctly ("first knot") was recorded; time started with the instruction and ended with completion of the first correctly performed knot. After successfully completing the knot, learners practiced tying the knot in isolation with no help from any outside source for a period of 5 minutes. After this practice period, learners were asked to tie 10 consecutive knots. The time to tie 10 consecutive knots and the accuracy of the knots (number of incorrectly constructed knots) were recorded. The number of knots (correct or incorrect) tied per minute was calculated for all 3 groups.

There were no first-learners who were unsuccessful at achieving the first knot during or after instruction. However, there were first learners who lost the ability to tie any knot during practice (the designated knot with or without errors). These learners were excluded from further participation in the study.

Teaching the second-learners and assessment of second-learner performance

First-learners were informed that they would be required to teach another student how to tie the knot after they completed their 10-knot trial. They were given no further instructions towards this task.

The performance of the second-learners was assessed in a manner similar to the way the performance of first-learners was assessed. Time to construct the first knot was recorded. This began at the beginning of first-learner instruction and ended with completion of the second-learners first knot. The second-learner was then given a 5-minute practice period in isolation and subsequently tested for time and accuracy of 10 consecutive knots. Number of knots (correct or incorrect) tied per minute was calculated for all 3 groups.

The teaching strategy used by the first-learner to teach the second-learner was evaluated. For O and OI groups first-learners, whether the first-learner followed all steps and repeated the steps to instruct the second-learner, as well as whether first-learners used TAG points or a marker were recorded.

After participation all of the learners were informed of the goals of the study. Learners who did not successfully achieve a locking, sliding knot were taught using an operant methodology until they were able to successfully tie the knot.

Statistics:

The median time (in seconds) to the first knot and average time to tie the 10-knots after practice between groups was compared using Kruskal-Wallis test. Performance of first- and second learners was compared using paired t-test. $P<0.05$ was considered statistically significant.

Results

Individual performance of first- and second-learners, as well as performance for each teaching group - traditional, operant, operant-informed - are shown in Table 2.

First-learners

All first-learners, immediately after instruction and independent of the teaching approach, were able to tie an accurate locking, sliding knot. Average and median time to tie the first knot accurately were different for the three groups; 152.5 and 127.5 sec in the T-group, 598.2 and 543 sec in the O-group and 712.9 and 693 sec in the OI-group (Kruskal-Wallis test, $p=0.007$). At the end of self-practice none of the 4 learners in the T group were able to accurately tie a locking, sliding knot. This was in comparison to 5 of 5 first-learners in the O group and 8 of 9 in the OI group. One first-learner in the T group and one first-learner in the OI group failed to construct any knot after their practice session. They were excluded from the study and their assigned

second learners were also excluded. In the 10-knot trial for first-learners, the error rate for the T group was 100%, compared to 0% in both the O and the OI group. Average time to tie the 10 knots and number of knots tied per minute were similar between the three groups (Table 2; Kruskal-Wallis test, p=0.336 and p=0.336, respectively).

Table 2. Performance of First- and Second Learners tying locking-sliding knots

Teaching Method	Learner	Time to 1st Knot (sec)	Practice		10-Knot trial Errors / 10 Knots		Time to 10 Knots (sec)	Knots per min
Traditional	1st	152	A	Unsuccessful	A	10 / 10	91	6.6
		44	B	Unsuccessful	B	10 / 10	109	5.5
		311	C	Unsuccessful	C	10 / 10	79	7.6
		103	D	Aborted	D	-	-	-
	Average	152.5		0 / 4 Successful		100% Errors	93.0	6.6
	2nd	358	A	Unsuccessful	A	10 / 10	73	8.2
		68	B	Unsuccessful	B	10 / 10	144	4.2
		72	C	Partially successful	C	8 / 10	80	7.5
		-	D	-	D	-	-	-
	Average	166.0		1 / 3 Successful		93% Errors	99	6.6
Operant	1st	559	E	Successful	E	0 / 10	113	5.3
		543	F	Successful	F	0 / 10	116	5.2
		527	G	Successful	G	0 / 10	108	5.6
		473	H	Successful	H	0 / 10	85	7.1
		889	I	Successful	I	0 / 10	139	4.3
	Average	598.2		5 / 5 Successful		0% Errors	112.2	5.5
	2nd	263	E	Successful	E	0 / 10	74	8.1
		461	F	Successful	F	0 / 10	109	5.5
		131	G	Successful	G	0 / 10	103	5.8
		49	H	Successful	H	0 / 10	106	5.7
		262	I	Successful	I	10 / 10	134	4.5
	Average	233.2		5 / 5 Successful		20% Errors	105.2	5.9
Operant informed	1st	570	J	Successful	J	0 / 10	105	5.7
		925	K	Successful	K	0 / 10	109	5.5
		786	L	Unsuccessful, Aborted	L	-	-	-
		517	M	Successful	M	0 / 10	92	6.5
		582	N	Successful	N	0 / 10	99	6.1
		458	O	Successful	O	0 / 10	75	8.0
		917	P	Successful	P	0 / 10	118	5.1
		693	Q	Successful	Q	0 / 10	99	6.1
		968	R	Successful	R	0 / 10	134	4.5
	Average	712.9		8 / 9 Successful		0% Errors	103.9	5.9

Teaching Method	Learner	Time to 1st Knot (sec)	Practice		10-Knot trial Errors / 10 Knots		Time to 10 Knots (sec)	Knots per min
	2nd	968	J	Successful	J	10 / 10	147	4.1
		809	K	Successful	K	0 / 10	102	5.9
		-	L	-	L	-	-	-
		501	M	Successful	M	0 / 10	115	5.2
		335	N	Successful	N	0 / 10	72	8.3
		565	O	Successful	O	0 / 10	97	6.2
		595	P	Successful	P	0 / 10	81	7.4
		290	Q	Successful	Q	0 / 10	114	5.3
		192	R	Successful	R	0 / 10	93	6.5
	Average	531.9		8 / 8 Successful		12.5% Errors	102.6	6.1

Second-learners

After practice and testing of the first-learners, 16 learner pairs remained, 3 in the T- group, 5 in the O-group and 8 in the OI-group. After instruction from the first-learners all 16 second-learners were able to tie a knot (although not necessarily an accurate knot). Average and median time to tie a first knot were different for the three teaching groups; 166 and 72 sec in the T-group, 233.2 and 262 sec in the O-group and 531.9 and 533 sec in the OI-group (Kruskal-Wallis test, p=0.041).

Traditional

After self-practice, only 1 of 3 second-learners in the T-group was able to tie the locking, sliding knot accurately and only 2 out of 10 times in the 10 knot trial. The 3 second-learners in the T-group had maintained an error in tying the correct knot that was introduced by their first-learner. Interestingly, one second-learner in the T-group was able to self-correct the error that had been introduced by the first-learner on the 9th and 10th attempt of the 10 knot trial.

Operant and Operant Informed

All 5 second-learners in the O-group and all 8 in the OI-group were able to tie the knot correctly after instruction and practice. During testing, one learner from the O-group and one from the OI-group each introduced an error and neither were able to construct any accurate knots.

Error Rates

In the 10-knot trial, the error rate for the T-group was 93% (2 correct out of 30 knots total), compared to 20% in the O-group (one learner comprised all 10 errors, there were 40 correct out of 50) and 12.5% in the OI-group (one learner comprised all 10 errors, there were 80 correct out of 90).

Time

Average time to tie the 10 knots and number of knots tied per minute were similar between the three groups (Table 2; Kruskal-Wallis test, p=0.788 and p=0.788, respectively).

Instruction of Second-Learners

Three first-learners of the T-group demonstrated the construction of the entire knot as a single task and each used demonstration to teach their second-learner.

The teaching strategy of O and OI first-learners to instruct second-learners was compared (Table 3). Of the 5 first-learners in the O group, 4 (80%) followed all of the steps that were used to originally teach them, including repeating each step five times. One first-learner included tag points, though inconsistently. None of the first-learners used markers.

First-learners in the OI group were specifically told during their own instructions that "the methods by which you are taught matter". Five (62.5%) first-learners followed all of the steps that were used to originally teach them, 7 (87.5%) used repetition of steps, 5 (62.5%) included tag points, and 4 (50%) used markers.

Comparison of first- and second-learners in the O group revealed that second-learners needed a shorter time to complete the first knot accurately (paired t-test, p=0.015), but time to achieve 10 knots and knots per minute were similar (p=0.503 and p=0.555, respectively). In the OI group, no differences were found between first and second-learners in time needed to complete the first knot accurately (paired t-test, p=0.212), time to tie 10 knots (p=0.913) and knots per minute (p=0.791).

Discussion

Surgical and orthopaedic communities have focused on creating learning platforms and effective teaching methodologies to train residents and students in surgical procedural skills[20]. While the role of residents as teachers has been discussed for more than 50 years[21] and the vital role of senior residents for the education of more junior residents and medical students has been well documented[5], less emphasis has been given to promoting teaching skills in early medical education.

This study showed that teaching medical students a simple surgical skill using an effective teaching methodology (operant reinforcement), which encompassed immediate feedback, repetition, and successive refinement, resulted in acquisition of skills that lasted over time within the learner. This was in contrast to traditional demonstration-based teaching which resulted in incomplete skills that deteriorated over time. Because operant reinforcement is formulaic and repetitive, we expected that the first-learners taught with operant-reinforcement would default to teaching the acquired skill with this same methodology. However, this study demonstrated that learners generally abandon the way they were taught when teaching a second-learner.

Operant methodologies have been used effectively for teaching precise motor skills as well as medical procedural skills[22-25] to novice learners. Further, compared to a demonstration-based learning group, learners in an operantly taught group achieve better precision performing the surgical skills, although the process is slower[15]. These findings are similar to the results seen in this study, in which traditionally taught learners

needed 2.5 minutes to tie the first knot compared to 11 minutes in the operant reinforcement groups. However, none of the 5 traditional learners were subsequently able to tie a locking, sliding knot accurately compared to 13/14 operant first-learners. In both studies, the "traditional" training approach failed to reliably teach the learners the surgical skill and showed that the operant methodology, based on learning with correction, repetition, and feedback, is advantageous for acquiring skills.

Table 3. Teaching approach used by First Learners to teach Second Learners

						2nd Learner		
Teaching Method	1st Learner	Followed All Steps Teaching	Repeated Steps Teaching	Used Tag Points	Used Marker Teaching	Errors	Time to 10 Knots	Knots/min
Operant	E	Yes	No	No	No	0 / 10	74	8.1
	F	Yes	Yes (5x)	No	No	0 / 10	109	5.5
	G	No	No	No	No	0 / 10	103	5.8
	H	Yes	No	No	No	0 / 10	106	5.7
	I	Yes	No	Yes*	No	10 / 10	134	4.5
		4/5 (80%)	1/5 (20%)	1/5 (20%)	0 (0)			
Operant Informed	J	Yes	Yes	Yes	Yes*	10 / 10	147	4.1
	K	Yes	Yes	Yes*	Yes	0 / 10	102	5.9
	M	Yes	Yes	Yes	No	0 / 10	115	5.2
	N	No	Yes	No	No	0 / 10	72	8.3
	O	Yes	Yes	Yes	Yes	0 / 10	97	6.2
	P	Yes	Yes	Yes	Yes*	0 / 10	81	7.4
	Q	No	Yes	No	No	0 / 10	114	5.3
	R	No	No	No	No	0 / 10	93	6.5
		5/8 (62.5%)	7/8 (87.5%)	5/8 (62.5%)	4/8 (50%)			
*, intermittently								

While first-learners in both the O- and OI-groups reliably taught second-learners to correctly tie the locking, sliding knot, (11 of 13 of the second-learners tying the knot correctly) first-learners did not reliably use the stepwise, positive reinforcement, operant techniques to teach the second-learner (Table 3). While a majority of O- and OI-first-learners taught all the steps, 0-20% of the O-protocol first-learners and 50-87.5% of the OI-protocol first-learners used step repetition, TAG points, or the marker. Each first-learner defaulted to their own individual and unique approach to teaching.

In both the O- and OI-groups, one second-learner failed. In both cases, the failure was a result of a first-learner not recognizing a mistake by the second-learner during construction of the knot that subsequently allowed errors in technique to propagate forward. This propagation emphasizes the

importance of preparing orthopedic surgery residents to be engaged and attentive teachers.

More OI-first-learners used aspects of operant reinforcement when they were told that that the method mattered. This result suggests that early exposure to teaching principles and techniques such as task analysis, marking, repetition, and scripts, will empower residents to make sure their second-learners achieve skill acquisition. We do not know how the skill will hold up over time nor do we know what happens when the second learner goes on to teach the third? This is of concern, as one of the most frequently used resources for junior residents when preparing for a case in the OR is advice from colleagues[26].

Helping medical professionals understand and develop educational skills early in their career will make them more proficient teachers and improve medical education. Medical education should thus emphasize not just the acquisition of reliable and accurate surgical skills, but also the elements of successful educational instruction. Physicians need to be exposed to teaching principles, skills, and techniques early during residency. Wilson outlined the obstacles to teaching effectively (a lack of knowledge of the principles of adult learning and teaching techniques) and proposed guidelines to facilitate surgical residents becoming capable instructors[11,27].

However, some progressive residency programs have adopted "residents-as-teachers" curricula[28]. These curricula have been shown to be effective in improving the teaching skills of the residents who participate[29-31]. Our study underscores the importance of these curricula for teaching the educational tools needed for the instruction of surgical skills.

There were several limitations to this study. It is difficult to recreate in experimental form the complexities of surgical skill acquisition and the interpersonal teaching environment amongst trainees. To mitigate this, the study focused on a single surgical skill and randomly grouped participants into pairs of first- and second-learners. Regarding teaching protocols, the subtle difference of the O- and OI-protocol may have been lost on the participants who were overwhelmed with new information emphasizing the role of residents as not just learners, but as future teachers. The control group protocol was perceived to be a generic representation of traditional surgical teaching, the so-called "see one, do one, teach one" method. In reality, this is difficult to standardize for experimental purposes. Additionally, the experimental design was constrained by the realities of enrolling medical student volunteers, whose availability is often limited by academic requirements. Ideally, each first-learner would have taught several second-learners allowing for better control of the individual teaching abilities of the first learners and outlier performances of the second learners. An experiment designed this way would require an unrealistically large number of participants. To better approximate the realities of learning in residency, the skill could have been taught, practiced, and then reinforced in subsequent sessions over a much longer timespan,

however, the study was limited by volunteer availability. Lastly, the volunteers for the study had enrolled in the medical school's orthopedic interest group and were thus a self-selecting cohort, though none reported prior experience tying a locking, sliding knot.

Conclusion

"See one, do one, teach one" is unreliable. The critical assumption that a learner who was taught using a structured methodology would successfully teach using that structured method was only partially true. While it is true that first-learners enabled the second-learners to reach the desired goal, in most cases, the teaching method was abandoned. This may have significant consequences when the teaching method is critical to avoiding unintended outcomes.

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Conflict of Interest Statement

The authors have indicated they have no potential conflicts of interest to disclose. Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/ licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

Ethical Review Committee Statement

This study received approval, exempt category 1, from the Institutional Review Board of Montefiore Medical Center/Albert Einstein College of Medicine. All investigations were conducted in conformity with ethical principles of research.

Location where the work was performed

This study was performed in the Department of Orthopaedic Surgery, Montefiore Medical Center, Bronx, NY, USA.

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