Multiple Uses for Procedural Simulators in Continuing Medical Education Contexts

Andrew R. Ruis[1](✉), Alexandra A. Rosser[1], Jay N. Nathwani[1], Megan V. Beems[1], Sarah A. Jung[1], and Carla M. Pugh[2]

[1] University of Wisconsin–Madison, Madison, WI, USA
arruis@wisc.edu
[2] Stanford University, Palo Alto, CA, USA

Abstract. Simulators have been widely adopted to help surgical trainees learn procedural rules and acquire basic psychomotor skills, and research indicates that this learning transfers to clinical practice. However, few studies have explored the use of simulators to help more advanced learners improve their understanding of operative practices. To model how surgeons with different levels of experience use procedural simulators, we conducted a quantitative ethnographic analysis of small-group conversations in a continuing medical education short course on laparoscopic hernia repair. Our research shows that surgeons who had less experience with laparoscopic surgery tended to use the simulators to learn and rehearse the basic procedures, while more experienced surgeons used the simulators as a platform for exploring a range of hernia presentations and operative approaches based on their experiences. Thus simple, inexpensive simulators may be effective with both novice and more experienced learners.

Keywords: Surgery education · Procedural simulation · Continuing Medical Education (CME) · Quantitative ethnography · Epistemic Network Analysis (ENA) · Discourse analysis

1 Introduction

Procedural simulations—models of surgical cases that enable individuals or teams to implement operative techniques—have been widely adopted to help trainees learn procedural rules and acquire basic psychomotor skills, and research indicates that this learning transfers to clinical practice (see, e.g., [1]). However, as Madani and colleagues [2] argue, mere possession of knowledge or mastery of individual skills in isolation is not sufficient for basic competency, let alone mastery; rather, expert surgeons must be able to integrate these and other elements of operative practice to achieve optimal patient outcomes. Although procedural simulation has been studied extensively as a platform for developing basic knowledge and skills, little research has explored its use with more advanced learners [3]. This raises an important question: *Can procedural simulations help more advanced learners continue their professional development beyond learning and rehearsing basic procedural knowledge and skills?*

B. Eagan et al. (Eds.): ICQE 2019, CCIS 1112, pp. 211–222, 2019.
https://doi.org/10.1007/978-3-030-33232-7_18

This question is particularly pressing, as current approaches to surgical education in the United States do not adequately help new surgeons develop the competency to successfully implement operative procedures [4]. In two separate studies, educators [5] and fellows [6] alike expressed a lack of confidence in current educational approaches, particularly in minimally invasive surgery. Moreover, graduating general surgery residents are poorly prepared to operate independently: of the 121 procedures considered essential by the majority of program directors, the average resident had performed only 18 of them more than 10 times prior to graduation; for fully half of the procedures (63), the mode number of times completing the procedure was zero, indicating that graduating residents have never independently completed many essential operations [7].

While these findings indicate a clear problem with how general surgery residents are trained—or with the expectations for what can be learned in five years or surgical residency—they also have significant implications for subsequent training and professional development, of which *continuing medical education* (CME) is a significant component [8, 9]. CME was originally designed to help licensed, practicing physicians *maintain* competency, but it must increasingly help them *develop* it as well.

The goal of this study was to understand the use of procedural simulation in one CME short course. To do this, we conducted a quantitative ethnographic analysis [10] of small-group conversations in two separate implementations of a course on laparoscopic hernia repair held annually at a large surgical conference in the United States. The six-hour course consisted of a two-hour lecture and a four-hour practicum in which small groups of participants used basic, box-style simulators to learn or review various laparoscopic hernia repair techniques with an expert instructor. Our research shows that surgeons who had less experience with laparoscopic surgery tended to use the simulators to learn and rehearse the basic procedural steps and rules, and to work on identifying and managing common errors. That is, they used the simulated case as an opportunity for *procedural rehearsal*. More experienced surgeons, in contrast, used the sim-ulators as a platform for discussing and exploring a range of hernia presentations and operative approaches based on their real-world experiences. That is, they used the simulated case as an opportunity for *procedural analysis*. Our findings suggest that relatively simple, inexpensive simulators may be effective with both novice and more experienced learners.

2 Methods

2.1 Setting and Participants

This study included 58 surgeons (53 practicing surgeons and 5 general surgery residents) who participated in a one-day CME course on laparoscopic inguinal and ventral hernia repair at a large surgical conference in the United States. Data were collected during two implementations of the course held in two different years. The course involved an introductory lecture (2 h) and a practicum (4 h). The lecture covered the basic procedural steps and rules of minimally invasive ventral and inguinal hernia repairs. During the practicum, participants were assigned to groups of three based on their self-reported prior experience with laparoscopic surgery (this process is described in more detail below). Each group worked with one or two randomly assigned instructors—experts in minimally invasive hernia repair—who provided instruction using simple box-style simulators developed for training in laparoscopic hernia repair procedures (see Fig. 1) [11]. All procedures were taught as mesh repairs; cautery was discussed only if participants broached the topic, but cauterization tools cannot be used with the simulators. The participant groups completed two sessions during the practicum, learning a different laparoscopic hernia repair procedure with a different instructor in each session.

Fig. 1. Box-style simulator and laparoscopic tools used in the hernia repair practicum.

2.2 Data Collection

Before beginning the course, participants reported their experience performing six common laparoscopic procedures: cholecystectomy, appendectomy, colectomy, incisional hernia repair, totally extraperitoneal hernia repair (TEP), and transabdominal preperitoneal hernia repair (TAPP). Participants indicated their experience using a five-point Likert scale, where one is "beginner", three is "competent", and five is "master surgeon". Participants' mean laparoscopic surgery experience (i.e., the mean of their self-ratings on all six procedures) ranged from 1.83 to 4.67. Participants were assigned to groups based on their mean experience so that groups were composed of surgeons with similar levels of laparoscopic surgery experience. Four researchers directly observed each practicum, and all sessions were audio and video recorded. Audio was transcribed manually, and each transcription was subsequently verified by a second transcriber. Audio transcripts were then coded for analysis.

2.3 Coding Process

Based on ethnographic observations and conventional content analysis of the transcribed audio data [12], we defined six codes (see Table 1) to identify key topics and epistemic elements in participant conversations. Automated coding algorithms were developed to code the transcribed audio data.

To assess the reliability of the coding process, two independent raters coded a case-controlled random sample of 40 turns of talk for each code, and the automated coding algorithm coded each sample as well. Raters assigned a "1" to any turn of talk in which the code was present, and a "0" to those in which it was not. To calculate inter-rater reliability, we computed Cohen's kappa (κ) for each code for all pairwise combinations of raters. To determine whether the kappa values obtained for the samples could be generalized to the entire dataset, we computed Shaffer's rho (ρ) to estimate the expected Type I error rate of kappa given the sample size [10, 13]. For each of the six codes, the rate of agreement was statistically significant ($\alpha = 0.05$) for a minimum kappa threshold of 0.65 (see Table 1).

Table 1. Discourse codes and inter-rater reliability statistics.

Code	Description & Example	Human 1 vs. Human 2		Human 1 vs. Computer		Human 2 vs. Computer	
		κ^a	*ρ(0.65)*	κ^a	*ρ(0.65)*	κ^a	*ρ(0.65)*
Mesh Repair	Referencing mesh, tacking, or suturing "One of those tacks fell; you did not have control of the tacker."	1.00	<0.01	1.00	<0.01	0.97	0.01
General Anatomy	Referencing the anatomy of the abdomen "Spermatic vessel is more lateral to the vas."	1.00	<0.01	1.00	<0.01	0.96	<0.01
Pathological Anatomy	Referencing the anatomy of a hernia "We've got to make sure the hernia is on the midline too because sometimes the hernia isn't on the midline."	0.95	0.01	0.98	<0.01	1.00	<0.01
Requesting Advice	Asking what surgeons should do in a given situation "So what do you do if it doesn't tack? What do you do in the operating room?"	0.86	<0.01	0.86	0.04	0.75	0.04
Trouble-shooting	Managing or negotiating complications "This is the tough side. We need to go to the easy side. The easy side is over there."	0.85	<0.01	0.89	<0.01	0.80	0.03

(*continued*)

Table 1. (*continued*)

Code	Description & Example	Human 1 vs. Human 2		Human 1 vs. Computer		Human 2 vs. Computer	
		κ^a	$\rho(0.65)$	κ^a	$\rho(0.65)$	κ^a	$\rho(0.65)$
Real-World Case	Referencing real bodies, patients, or other cases "So that can be done with a suture passer and a suture … if the patient is thin enough that you can see the fascia."	0.80	0.02	0.95	0.01	0.73	<0.01

[a] *All kappas are statistically significant for $\rho(0.65) < 0.05$.*

2.4 Epistemic Network Analysis

For the purposes of analysis, participants were divided into quartiles based on their mean laparoscopic surgery experience ratings. Participants with mean laparoscopic surgery experience scores less than or equal to 2.50 (lowest quartile, $n = 13$) were classified as *novices*, as their self-ratings indicated that they did not feel fully competent with common laparoscopic procedures. Participants with mean laparoscopic surgery experience scores greater than 3.00 (highest quartile, $n = 17$) were classified as *relative experts*, as their self-ratings indicated that they felt generally competent with common laparoscopic procedures. The participants in the second and third quartiles ($n = 23$) were classified as *intermediates*. Seven participants did not report their experience with minimally invasive surgery.

Epistemic network analysis (ENA) version 1.5.2 was used to analyze the conversations of novices, intermediates, and relative experts [10, 14–16]. We defined the units of analysis as all lines of data associated with a single participant (excluding instructors). The ENA algorithm uses a moving window to construct a network model for each line in the data, showing how codes in the current line are connected to codes that occur within the recent temporal context [17]. In this study, the window was defined as 5 utterances (each turn of talk plus the 4 previous turns) within a given practicum session. The resulting networks were aggregated for each unit of analysis in the model. In this model, networks were aggregated using a binary summation in which the networks for a given line reflect the presence or absence of the co-occurrence of each unique pair of codes. The networks in the ENA model were normalized for all units of analysis before they were subjected to a dimensional reduction, which accounts for the fact that different participants may have different numbers of coded utterances. For the dimensional reduction, we used a singular value decomposition (SVD), which produces orthogonal dimensions that maximize the variance explained by each dimension.

Networks were visualized using network graphs where nodes correspond to the codes, and edges reflect the relative frequency of co-occurrence, or connection, between two codes. The result is two coordinated representations for each unit of analysis: (1) an ENA score, or a point that represents the location of that unit's network in the projected space formed by the first two dimensions in the SVD, and (2) a weighted network graph projected into the same low-dimensional space. The positions of the network graph nodes are fixed, and the node positions are determined by an optimization routine that attempts to produce a high degree of correspondence between the ENA scores of the units and the corresponding network centroids. To do this, the optimization routine uses a least-squares approach that minimizes the sum of squared distances between the network centroids and the ENA scores on each dimension. Because of the co-registration of network graphs and projected space, the positions of the network graph nodes can be used to interpret the dimensions of the projected space and explain the positions of different units in the space. Our model has co-registration correlations (Pearson's and Spearman's r) of >0.93 on the first and second SVD dimensions. These measures indicate that there is a strong goodness of fit between the visualization and the original model.

3 Results

Figure 2 shows the ENA scores and difference graph for novices and relative experts. The novices appear primarily in the upper part (high y values) of the ENA space formed by the first two SVD dimensions, while the relative experts appear mostly in the lower part of the space (low y values). The first and second SVD dimensions account for 24.0% and 15.1% of the variance in patterns of connectivity, respectively.

To understand this difference between novices and relative experts, we plotted the difference graph for the two groups (see Fig. 2, bottom). For the novices, the most distinguishing connections were from *Requesting Advice* to *General Anatomy*, *Mesh Repair*, and *Troubleshooting*. That is, the novices focused mostly on the procedural aspects of the simulated case: asking questions about basic anatomy, about the procedural steps and rules, and about managing errors or complications. The relative experts, in contrast, made proportionately stronger connections to *Real-World Case* and *Pathological Anatomy*. Like the novices, the relative experts discussed the overall anatomy relevant to any abdominal procedure (*General Anatomy*), but they focused more on the anatomy specific to the hernia (*Pathological Anatomy*). Moreover, the relative experts were more likely than novices to discuss and ask questions about the procedure and the anatomy in the context of real-world cases or scenarios. These patterns of conversation suggest that relative experts used the simulators less as an opportunity to learn the surgical procedure or practice implementing the procedural steps, and more as an opportunity to discuss specific hernia repair issues that arise in actual cases. In other words, the novices used the simulators in the traditional sense—to learn the operative rules of the modeled hernia repair and rehearse key skills and techniques—while the relative experts treated each simulated case as a specific instantiation of a broader class of operative problem, using it to explore how expert surgeons adapt to different clinical presentations.

These differences are evident in the qualitative data as well. For example, consider the following excerpt from a conversation among novices.

Line 1 Novice 1: *So, the principle, is the mesh going to cover everything?*

Line 2 Instructor: *That's right, the mesh going to cover everything. Alright, so let's look over here again. Let's see, are your vas and vessels separated?*

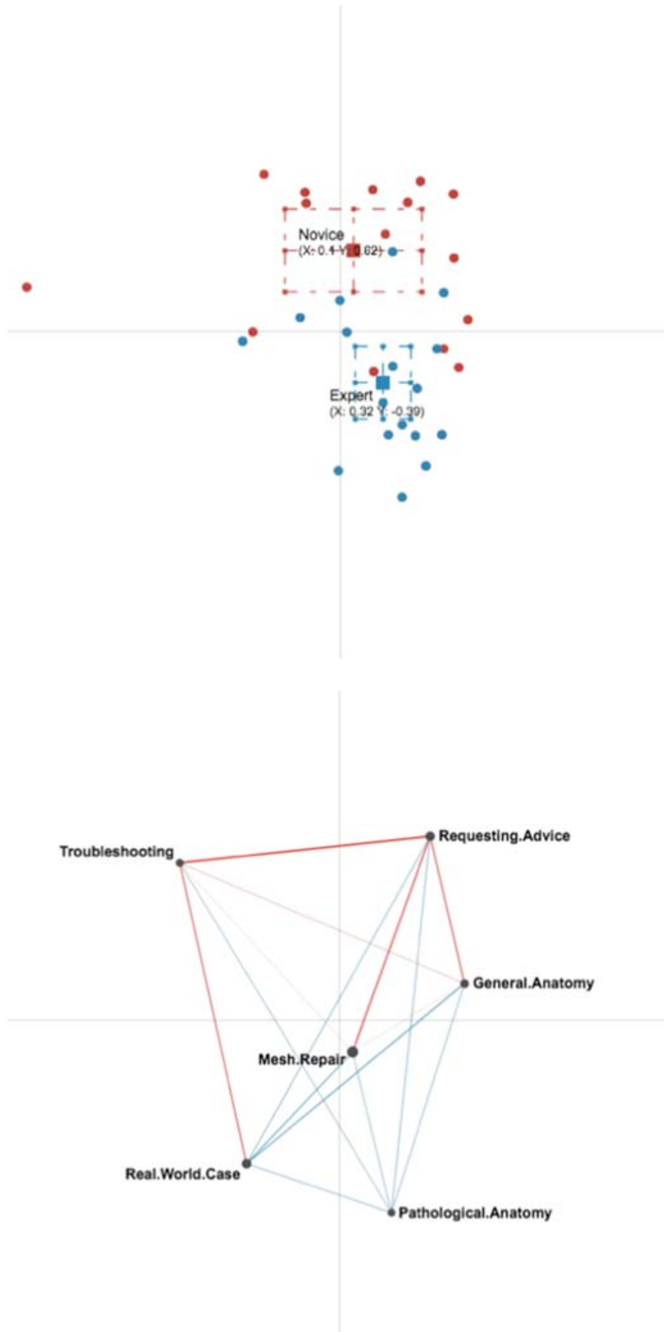

Fig. 2. TOP: ENA scores on the first and second dimensions (points) for novices (red) and relative experts (blue) with means (squares) and 95% confidence intervals (dashed boxes). BOTTOM: Difference graph of the novice and relative expert mean networks (Color figure online).

Line 3 Novice 2: *This is the vas here?*
Line 4 Instructor: *That's the vas.*
Line 5 Novice 1: *You are still in the wrong plane.*
Line 6 Instructor: *Yeah, you have to cut the white [fascia].*
Line 7 Novice 1: *I thought we did cut the white.*
Line 8 Novice 2: *I thought we did. That's what I was originally going into. Was going to practice with the balloon. Now we need the trocar in below it*

This excerpt begins with a participant asking a question about the mesh (Line 1). The instructor replies by orienting the participant to the basic anatomy associated with the procedure (Lines 2–4). A second participant identifies an error with the procedure (Line 5) and works with the others to find a solution (Lines 6–8). In this brief excerpt, the novices focus on a specific procedural step—placing the mesh—which requires understanding the anatomy, properly orienting the endoscope, and managing errors as they occur. In addition, novice conversations involve more reiteration and requests for basic information. As this example shows, novices tended to use the simulated case as an opportunity to learn and rehearse the basic procedural steps and fundamental skills of laparoscopic hernia repair.

In contrast, the relative experts tended to draw more on their own experience with laparoscopic hernia repair, as the following excerpt illustrates.

Line 1 Expert 1: *I do a lot of melanoma patients that I have had with superficial internal dissection. ... In theory, their complication is a pulled femoral hernia. Would that just be sufficient to cover up the hole?*
Line 2 Instructor: *If I've over-dissected the space ... then I'll fixate... with a tack that covers medially and a really one high lateral tack.*
Line 3 Expert 1: *So what do you do there? I mean, do you just kind of move the mesh down lower to make sure it's covered?*
Line 4 Instructor: *So, so if you've got a femoral, you should dissect that space out and cover it*

This excerpt begins with the participant asking a question about specific hernia pathology based on prior cases (Line 1). The instructor then responds by outlining strategies for tacking the mesh (Line 2). The participant asks a follow up question about mesh placement (Line 3), and the instructor addresses how to achieve coverage. In comparison to the novices, the relative experts were less focused on the procedure in front of them and more on using it as a platform to talk—and think—about real clinical scenarios, often ones that they experience in practice. Their conversations extended beyond discussion of basic procedural steps or skills; in Line 3, for example, even though the participant is asking about a procedural step (mesh placement), he does so in the context of a more complex clinical presentation that he sees in his practice.

4 Discussion

This study examined how surgeons with different levels of experience in laparoscopic surgery used basic procedural simulators in a CME short course. While surgeons with less experience used the simulators to learn and rehearse the procedural rules and basic laparoscopic skills, as evidenced by the strong connections they made from *Requesting Advice* to *General Anatomy*, *Mesh Repair*, and *Troubleshooting*, more experienced surgeons used the simulators to explore various hernia presentations and best practices for addressing them, as evidenced by the strong connections they made to *Real-World Case* and *Pathological Anatomy*. In other words, novices engaged in *procedural rehearsal*—seeking to develop basic knowledge and skills—while the relative experts engaged in *procedural analysis*—using the simulated case as a platform with which to explore different hernia presentations or operative challenges they experience in practice.

This suggests that there are two primary functions that procedural simulators can serve. The first, and the one most commonly acknowledged, is that they enable surgeons and surgical trainees to learn and rehearse a specific operative procedure or the associated skills and best practices in a setting that involves no risk to patients, that provides useful feedback, and that is low-cost and logistically feasible. The novices in this study used the simulators primarily in this way. The second function the procedural simulators serve is to facilitate a guided version of what Schön calls *reflection in action* [18]. Reflection-in-action takes place as experts in a domain (a) identify similarities between novel problems and past problems, (b) adapt the solutions from those past problems based on their understanding of the current problem, and then (c) evaluate the results of applying the adapted solution to the problem at hand. The relative experts in this study used the simulators as a platform for engaging in reflection-in-action with the guidance of their peers and a more experienced instructor. That is, they drew on past experiences to pose questions and construct scenarios, and then used the simulated case to work through how to solve those problems with the guidance of an even more experienced surgeon.

Facilitation of reflection in this way is an important affordance of procedural simulation that requires further study [3]. While numerous interventions and training protocols have been used to promote reflective practice and prepare clinicians to be self-directed, lifelong learners (see, e.g., [19–21]), reflective practice was found to be negatively correlated with physician age and experience [22]. This suggests that reflection on practice may decline as surgeons progress in their careers. CME courses grounded in procedural simulation could provide an effective mechanism for promoting on-going reflection among practicing surgeons.

Of course, this study has several limitations. First, the sample size is small, and we studied only one CME course that uses only one type of procedural simulator. Thus, our conclusions cannot be generalized without further research on learning across a range of CME course and simulation models. However, small-group practica are very common in CME contexts, and our research suggests that grouping participants by expertise may facilitate more productive learning interactions. This is critical, as many

CME courses are quite short, and many physicians have limited time for ongoing training. Future research should explore the affordances and limitations of this approach.

Second, this study modeled learning processes by analyzing participant conversations, but there was no outcome measure. Thus, we were unable to assess the extent to which the course helped participants develop knowledge, skills, or other competencies. This is a broader problem with CME as it is implemented in the United States. Few CME courses assess learning, and it is difficult to control for the effects of CME courses in longitudinal studies that document changes in clinical skill or practice. While there is limited evidence that simulation is more effective in CME contexts than traditional approaches to clinical education [23], the basic CME model is not particularly effective for changing physician behavior or improving patient health outcomes [24]. Considerably more research is needed on CME in particular and, more generally, on how physicians develop and maintain expertise over the course of their careers [9, 25]. We argue that quantitative ethnography provides a method and a set of tools for exploring such learning processes, and prior research has shown that it could provide an effective means of assessing operative competency as well [26].

Lastly, this study did not explore the role that instructors played in guiding participant conversations. While instructor discourse was included in the analysis, the instructors themselves were not included as units. Research on this same data has found, for example, that instructors were significantly more likely to answer questions with anecdotes when responding to relative experts and with prohibitions (what not to do) when responding to novices [27]. In future research, we will explore in more detail the relationship between teaching practices and learning processes in order to understand better the effects of instructional strategies on learning with procedural simulators.

Despite these limitations, our findings suggest that inexpensive, basic procedural simulators, such as the box-style simulators used by participants in this study, can help both novices and more experienced surgeons improve their understanding of operative practices by facilitating both rehearsive and reflective practice.

Acknowledgements. This work was funded in part by the National Science Foundation (DRL-1661036, DRL-1713110), the Wisconsin Alumni Research Foundation, and the Office of the Vice Chancellor for Research and Graduate Education at the University of Wisconsin-Madison. A. R. Ruis was supported by a University of Wisconsin-American College of Surgeons Education Research Fellowship. The opinions, findings, and conclusions do not reflect the views of the funding agencies, cooperating institutions, or other individuals.

References

1. Dawe, S.R., Windsor, J.A., Broeders, J.A., Cregan, P.C., Hewett, P.J., Maddern, G.J.: A systematic review of surgical skills transfer after simulation-based training: laparoscopic cholecystectomy and endoscopy. Ann. Surg. **259**, 236–248 (2014)
2. Madani, A., et al.: What are the principles that guide behaviors in the operating room? creating a framework to define and measure performance. Ann. Surg. **265**, 255–267 (2017)

3. Sullivan, S.A., Ruis, A.R., Pugh, C.M.: Procedural simulations and reflective practice: meeting the need. J. Laparoendosc. Adv. Surg. Tech. **27**, 455–458 (2017)
4. Mattar, S.G., et al.: General surgery residency inadequately prepares trainees for fellowship: results of a survey of fellowship program directors. Ann. Surg. **258**, 440–449 (2013)
5. Subhas, G., Mittal, V.K.: Minimally invasive training during surgical residency. Am. Surg. **77**, 902–906 (2011)
6. Osman, H., Parikh, J., Patel, S., Jeyarajah, D.R.: Are general surgery residents adequately prepared for hepatopancreatobiliary fellowships? a questionnaire-based study. HPB **17**, 265–271 (2015)
7. Bell, R.H.: Operative experience of residents in us general surgery programs: a gap between expectation and experience. Ann. Surg. **249**, 719–724 (2009)
8. Iyasere, C.A., Baggett, M., Romano, J., Jena, A., Mills, G., Hunt, D.P.: Beyond continuing medical education: clinical coaching as a tool for ongoing professional development. Acad. Med. **91**, 1647–1650 (2016)
9. Sachdeva, A.K.: The new paradigm of continuing education in surgery. Arch. Surg. **140**, 264–269 (2005)
10. Shaffer, D.W.: Quantitative Ethnography. Cathcart Press, Madison (2017)
11. Pugh, C., Plachta, S., Auyang, E., Pryor, A., Hungness, E.: Outcome measures for surgical simulators: Is the focus on technical skills the best approach? Surgery **147**, 646–654 (2010)
12. Hsieh, H.-F., Shannon, S.E.: Three approaches to qualitative content analysis. Qual. Health Res. **15**, 1277–1288 (2005)
13. Eagan, B.R., Rogers, B., Pozen, R., Marquart, C., Shaffer, D.W.: rhoR: Rho for inter rater reliability (2016)
14. Marquart, C., Hinojosa, C.L., Swiecki, Z., Eagan, B.R., Shaffer, D.W.: Epistemic network analysis (2019)
15. Shaffer, D.W., Collier, W., Ruis, A.R.: A tutorial on epistemic network analysis: analyzing the structure of connections in cognitive, social, and interaction data. J. Learn. Anal. **3**, 9–45 (2016)
16. Shaffer, D.W., Ruis, A.R.: Epistemic network analysis: a worked example of theory-based learning analytics. In: Lang, C., Siemens, G., Wise, A.F., and Gasevic, D. (eds.) Handbook of Learning Analytics, pp. 175–187. Society for Learning Analytics Research (2017)
17. Siebert-Evenstone, A.L., Irgens, G.A., Collier, W., Swiecki, Z., Ruis, A.R., Shaffer, D.W.: In search of conversational grain size: modelling semantic structure using moving stanza windows. J. Learn. Anal. **4**, 123–139 (2017)
18. Schön, D.A.: The Reflective Practitioner: How Professionals Think in Action. Basic Books, New York (1983)
19. McGlinn, E.P., Chung, K.C.: A pause for reflection: Incorporating reflection into surgical training. Ann. Plast. Surg. **73**, 117 (2014)
20. Jordan, M.E., McDaniel Jr., R.R.: Managing uncertainty during collaborative problem solving in elementary school teams: the role of peer influence in robotics engineering activity. J. Learn. Sci. **23**, 490–536 (2014)
21. Husebø, S.E., O'Regan, S., Nestel, D.: Reflective practice and its role in simulation. Clin. Simul. Nurs. **11**, 368–375 (2015)
22. Mamede, S., Schmidt, H.G.: Correlates of reflective practice in medicine. Adv. Health Sci. Educ. **10**, 327–337 (2005)
23. McGaghie, W.C., Issenberg, S.B., Cohen, M.E.R., Barsuk, J.H., Wayne, D.B.: Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? a meta-analytic comparative review of the evidence. Acad. Med. **86**, 706–711 (2011)

24. Davis, D., O'Brien, M.A.T., Freemantle, N., Wolf, F.M., Mazmanian, P., Taylor-Vaisey, A.: Impact of formal continuing medical education: do conferences, workshops, rounds, and other traditional continuing education activities change physician behavior or health care outcomes? J. Am. Med. Assoc. **282**, 867–874 (1999)
25. Sachdeva, A.K., Blair, P.G., Lupi, L.K.: Education and training to address specific needs during the career progression of surgeons. Surg. Clin. North Am. **96**, 115–128 (2016)
26. Ruis, A.R., Rosser, A.A., Quandt-Walle, C., Nathwani, J.N., Shaffer, D.W., Pugh, C.M.: The hands and head of a surgeon: modeling operative competency with multimodal epistemic network analysis. Am. J. Surg. **216**, 835–840 (2018)
27. Godfrey, M., Rosser, A.A., Pugh, C.M., Shaffer, D.W., Sachdeva, A.K., Jung, S.A.: Teaching practicing surgeons what not to do: an analysis of instruction fluidity during a simulation-based continuing medical education course. Surgery **165**, 1082–1087 (2019)