Collaborative learning of clinical skills in health professions education: the why, how, when and for whom

Martin G Tolsgaard,[1,2] Kulamakan M Kulasegaram[3] & Charlotte V Ringsted[4]

OBJECTIVES This study is designed to provide an overview of why, how, when and for whom collaborative learning of clinical skills may work in health professions education.

WHY Collaborative learning of clinical skills may influence learning positively according to the non-medical literature. Training efficiency may therefore be improved if the outcomes of collaborative learning of clinical skills are superior or equivalent to those attained through individual learning.

HOW According to a social interaction perspective, collaborative learning of clinical skills mediates its effects through social interaction, motivation, accountability and positive interdependence between learners. Motor skills learning theory suggests that positive effects rely on observational learning and action imitation, and negative effects may include decreased hands-on experience. Finally, a cognitive perspective suggests that learning is dependent on cognitive co-construction, shared knowledge and reduced cognitive load.

WHEN AND FOR WHOM The literature on the collaborative learning of clinical skills in health science education is reviewed to support or contradict the hypotheses provided by the theories outlined above. Collaborative learning of clinical skills leads to improvements in self-efficacy, confidence and performance when task processing is observable or communicable. However, the effects of collaborative learning of clinical skills may decrease over time as benefits in terms of shared cognition, scaffolding and cognitive co-construction are outweighed by reductions in hands-on experience and time on task.

CONCLUSIONS Collaborative learning of clinical skills has demonstrated promising results in the simulated setting. However, further research into how collaborative learning of clinical skills may work in clinical settings, as well as into the role of social dynamics between learners, is required.

Medical Education 2016: 50: 69–78
doi: 10.1111/medu.12814

Discuss ideas arising from the article at http:// www.mededuc.com discuss.

[1]Centre for Clinical Education, Capital Region and University of Copenhagen, Copenhagen, Denmark
[2]Department of Obstetrics and Gynaecology, Nordsjælland's Hospital Hillerød, Denmark
[3]Wilson Centre, Department of Family and Community Medicine, University Health Network, University of Toronto, Toronto, Ontario, Canada
[4]Faculty of Health, University of Aarhus, Aarhus, Denmark

Correspondence: Martin G Tolsgaard, Centre for Clinical Education, Copenhagen University Hospital Rigshospitalet, Blegdamsvej 9, Copenhagen 2100 OE, Denmark. Tel: 00 45 61 30 30 72; E-mail: martintolsgaard@gmail.com

INTRODUCTION

A broad definition of collaborative learning is learning that takes place in a situation in which 'two or more people work together in order to learn something'.[1] In the context of collaborative learning of clinical skills, 'people' include health professionals and 'something' includes cognitive, technical and non-technical skills related to patient care.[2] Cooperative and collaborative learning are often distinguished based on the level of interaction between learners, whereby cooperative learning may refer to splitting an activity between learners and collaborative learning involves learners working together on a task.[1] In the interests of clarity, the term 'collaborative learning' will be used for both conditions throughout this review.

Collaborative learning of content knowledge is a prevailing concept in health professions education and occurs in a variety of formats of small-group learning, including problem-based learning (PBL) and team-based learning (TBL). Similar formats for clinical skills learning are not very common. However, an increasing number of studies on the collaborative learning of clinical skills, particularly in the context of simulation, have recently emerged with promising results.[3]

In this article, we review the role of collaborative learning of clinical skills in health professions education. First, we will review the pragmatic and pedagogical background for collaborative learning of clinical skills (the *why*). We will provide a synthesis of existing theories that support the use of collaborative learning of clinical skills to generate a set of hypotheses regarding its effective components and prerequisites (the *how*). Then, we will seek evidence that supports or contradicts these hypotheses based on existing medical education literature to develop a theoretical framework that can be used to guide educators in facilitating effective and efficient collaborative learning of clinical skills (the *when* and *for whom*). Finally, we will provide suggestions for future research.

Methodological considerations

This narrative review is not intended as an exhaustive description of all learning theories on collaborative learning and nor is it a systematic review of collaborative learning of clinical skills. For the section on *how*, we searched for learning theories that made explicit predictions and allowed empirical evaluation using a snowballing technique. We aimed for a broad sampling strategy that would enable the representation of theories from multiple schools of thought in order to provide a wide perspective on *how* the collaborative learning of clinical skills may work. For the sections on *when* and *for whom*, we searched MEDLINE, ERIC and SCOPUS for studies involving the collaborative learning of clinical skills using keywords related to collaborative learning (e.g. 'dyad practice', 'collaborative learning', 'cooperative learning', 'peer-assisted learning', 'group learning'). Finally, we searched the reference lists of included studies to identify additional studies. Studies involving the collaborative learning of clinical skills in health professions education were included according to the definitions given above. Studies describing the collaborative learning of content knowledge, including in PBL and TBL, were not included in this review. The distinction between collaboration for content knowledge learning and that for clinical skills learning was made because the latter often involves a complex mix of diagnostic, behavioural, motor and communication skills that need to be applied in a variety of different clinical contexts.

The findings from the medical education literature were compared and contrasted with the hypotheses generated from existing collaborative learning theories. Finally, a theoretical model for collaborative learning of clinical skills was constructed based on supporting and contradicting evidence.

Why collaborative learning of clinical skills?

From an efficiency-based point of view, there are several advantages to the collaborative learning of clinical skills. Much undergraduate and postgraduate clinical skills training takes place in clinical skills laboratories or in clinical workplace-based settings, which may require the use of expensive simulators and clinical teacher resources. Training efficiency may therefore be improved if the outcomes of collaborative learning of clinical skills are equivalent or superior to those attained through individual learning.

From a pedagogical perspective, there are several potential advantages to collaborative learning of clinical skills. Motor skills learning literature has suggested that working in pairs may produce learning gains equivalent to those achieved by working alone[4] and research on TBL and PBL demonstrates positive results of collaborative efforts for content knowledge learning.[5] However, when learning cannot be proceduralised and relies heavily on declarative knowledge, collaboration may produce inferior learning outcomes compared with individual practice.[6] Collaborative learning of clinical skills is therefore not a panacea and its effectiveness may depend on the type of learners, task, learner interactions and settings. The complex mechanisms of action and interactions between factors that enhance and impede the outcomes of collaborative learning of clinical skills are clarified further in the following sections.

How does collaborative learning work?

There are multiple theories with broad philosophical roots that help explain how and when collaborative learning works. The philosophical roots include theories following the traditions of Marx, Heidegger and Wittgenstein, who give rise to approaches to collaborative learning based on social, situated, and linguistic perspectives.[7] More recent frameworks help us to understand how the collaborative learning of clinical skills works, and include frameworks within the motor skills learning literature, and research from cognitive psychology and neuroscience. In this paper, we describe the theoretical foundations of collaborative learning of clinical skills from three overarching perspectives: the *social interaction perspective*; the *motor skills learning perspective*, and the *cognitive perspective*. These perspectives help us to embrace theories from different schools of thought and allow for the representation of historic as well as contemporary theories. As the literature on collaborative learning numbers more than 1200 items published over the past century,[8] the theories included in this paper are not exhaustive, but instead represent examples of the mechanisms by which collaboration may support skills learning in health professions education.

THE SOCIAL INTERACTION PERSPECTIVE ON COLLABORATIVE LEARNING

The social interaction perspective on collaborative learning assumes some kind of interaction between learners. One of the widely used approaches to explaining collaborative learning is provided by Vygotsky's social-cultural theory.[9] Central to this perspective is the interaction between learners and more knowledgeable others or peers, which enables the learners to perform tasks that they cannot yet perform on their own. The difference between the learner's actual level of development and the level at which the learner may perform during appropriate guidance is termed the 'zone of proximal development'. This represents the learning potential that may be elicited from the interaction between the learner and a more knowledgeable peer. The realisation of differences and disagreements through social interaction is also central to Piaget's notion of socio-cognitive conflict. This conflict may prompt the learner to shape and reshape his or her ideas, which eventually leads to more advanced levels of cognition and learning.[10]

According to social learning theory, learners may also benefit from observation of others, which allows the reproduction and imitation of actions performed by a peer. Observing actions that lead to undesirable outcomes may enable learners to adjust their own actions to avoid repeating the same errors during subsequent practice. Consequently, collaboration may benefit learning even when learners and observed peers are novices and errors are committed during training.[11] Moreover, social interaction can positively affect learners' self-efficacy and motivation,[12] which in turn may affect subsequent learning and performance. Improvements in motivation are, however, only observed if the task is dependent on the sum of all group members' learning rather than on a single group product,[13] which may be explained by different levels of social accountability.

Accountability and social cohesion are among the principal proponents of Johnson and Johnson's social interdependence theory.[8] Social interdependence exists when outcomes for individuals are affected by their own and others' actions. This interdependence may be positive or negative depending on whether actions of individuals promote or obstruct group goals, which again may depend on the level of common goals, common outcomes and interpersonal bonds between group members. Improvements in performance or achievements do not derive just from being part of a group, but rely on positive interdependence. Positive interdependence is thought to simulate individual accountability and responsibility, as well as to reduce social loafing. However, in larger groups, learners are less likely to perceive their own contributions as essential to group success and individual accountability is therefore thought to be inversely correlated to group size.[14] Finally, negative interdependence may follow from collaboration in highly competitive structured environments in which learners perceive that they can be successful only if others fail to achieve their goals.[15]

THE MOTOR SKILLS LEARNING PERSPECTIVE ON COLLABORATIVE LEARNING

Observational learning is central to social learning theory, but is also at the core of literature on collaborative motor skills learning. Whereas social learning theory emphasises the effects of observation through attention, memory and motivation, the motor skills learning literature explains the effects of observation through action imitation and internal representation. From a theoretical perspective, social learning theory uses behavioural and cognitive frameworks to explain the effects of observation, whereas research on motor skills learning is often grounded in neuroscience and neuroimaging. The motor skills learning literature provides several examples of the effectiveness and efficacy of training in complex skills in pairs, also called dyads. Shebilske *et al.*[16] compared the effects of dyad practice, in which participants each played one half of a computer game by taking turns to control the joystick, with those of individual practice in which participants handled the task alone. Although dyad participants received only half the amount of hands-on practice, they performed similarly to participants who had practised alone on a subsequent individual performance test.[16] In the study by Shebilske *et al.*[16] and in subsequent replication studies, dyad practice doubled training efficiency despite providing only half the amount of hands-on practice of participants who practised individually. In a study involving a stabilometer, Shea *et al.*[17] compared the effects of learning in dyads who alternated turns as active participants and observers after each trial with those in dyad controls who completed all practice trials in one role before switching roles. When different forms of training were performed consecutively, acquisition and retention were impaired in comparison with those in dyads who alternated between observation and active practice. These differences were explained by more effective use of rest periods, along with partner observation and dialogue.[17] Granados and Wulf[18] examined the relative contributions of dialogue and observation to the effectiveness of dyad practice and demonstrated that the opportunity to observe another learner seemed to be responsible for the advantages of dyad practice.

Observational learning has been demonstrated to be beneficial in the learning of complex skills. Although observational learning is not as effective as physical practice, it allows learners to extract important information on the effectiveness of different strategies and appropriate coordination patterns, as well as providing opportunities to identify and correct errors.[4,17,18] A neurophysiological basis for learning by observation and imitation has been provided through the mirror neuron mechanism. Mirror neurons are a particular class of visuomotor neuron located in the premotor cortex that respond to observation of action performed by others, as well as to action performed by oneself. The function of the mirror neuron system may involve action understanding and imitation during complex skills learning, which lets learners practise without actual hands-on involvement.[19] Reduced hands-on experience may, however, come at a price. According to theory on motor skills learning, learners move from cognitive stages of effortful movement execution to increasing levels of automaticity with sustained practice.[20] However, automaticity requires a great deal of practice and any reductions in the amount of actual hands-on practice that occur in consequence to the shifting of turns as the active participant may delay or prevent it.

THE COGNITIVE PERSPECTIVE ON COLLABORATIVE LEARNING

The cognitive perspective on collaborative learning includes theories on how information is processed, encoded, retrieved and restructured during interactions with other learners.

Cognitive load theory describes how and when collaborative learning may be effective.[21] Cognitive load theory relies on the notion that learners have limited cognitive processing capacity and that working memory is considered a bottleneck for information processing. Consequently, if tasks are too cognitively demanding, schema construction and automation in long-term memory are hindered.[22] The degree to which a task is too cognitively demanding may vary according to the level of the learner. For example, a novice medical student may struggle to establish a peripheral intravenous access while talking to the patient, whereas the same task requires few cognitive resources for a first-year resident. According to evolutionary cognitive load theory, humans have evolved to communicate with others and to borrow and reorganise information from other people's long-term memories. Learners may divide the cognitive load caused by a task (known as the *intrinsic* load) with others and thereby distribute information processing across a larger reservoir of cognitive capacity. However, coordination and communication between learners during task performance may in itself contribute to the cognitive load. This may be either helpful (beneficial to *germane* load) or ineffective (increasing the *extraneous* load) to the learning process. Collaboration may be effective if the advantages of shared cognitive capacity outweigh the cognitive costs associated with efforts to maintain communication and coordination between learners (known as *transaction costs*).[23] For highly complex tasks, dividing information processing across a larger reservoir of cognitive capacity may therefore improve learning. For less complex tasks, by contrast, individual learning may be the most effective strategy because it does not require learners to use additional cognitive efforts on communication and coordination with peers.[22,23] Hence, in this view, the main determinant of the outcomes of collaborative learning is task complexity.

Moving from the post-positivist view on cognition and teaching efficiency into a constructivist framework may offer a different view on cognition and collaboration. The *active–constructive–interactive* framework proposed by Chi describes how overt activities may foster different types of cognitive processing and stimulate increasing levels of learning.[24] Whereas cognitive load theory focuses on how to design learning *materials* and *environments* that may positively affect learning, the active–constructive–interactive framework describes how to foster *activities* that benefit learning. *Active* activities may involve engaging learners in doing something physically such as repeating the to-be-learned material, which may help in the encoding of new information.[25] During *constructive* activities, learners actively build mental models of the to-be-learned information, which may help them to integrate new knowledge with existing knowledge. Finally, *interactive* activities involve the co-construction of knowledge and scaffolding that allows learners to incorporate their partners' contributions into their own mental representations of complex problems. Interactive activities may also include active and constructive activities and are suggested to produce the most effective information-processing activity for learning. However, in tasks that rely heavily on declarative knowledge that cannot be proceduralised, collaborative learning can be inferior to individual learning.[6] Hence, declarative knowledge requires deep, often meaningful processing that may still be difficult to observe. Whether this hinders or later integrates with interaction, knowledge co-construction and scaffolding is unknown.

HYPOTHESES ON THE COLLABORATIVE LEARNING OF CLINICAL SKILLS IN THE HEALTH PROFESSIONS

Different hypotheses may be generated from these theories with regard to how the collaborative learning of clinical skills may work. According to the social interaction perspective:

1 Outcomes of collaborative learning of clinical skills depend on the quality of interaction between learners and the level of positive interdependence.
2 Positive effects on learning are mediated through improved self-efficacy, motivation and social support.

Adding to the social interaction perspective, the motor skills learning literature predicts that:

3 Beneficial effects of collaborative learning of clinical skills rely on action imitation and understanding gained through interchanging periods of observation and actual hands-on practice.
4 Reduced hands-on experience may impair skills automaticity during later stages of learning.

Finally, according to the cognitive perspective:

5 Collaborative learning of clinical skills is effective for complex learning tasks or skills characterised by high cognitive load, but less effective or ineffective for simple skills associated with low cognitive load.
6 Interaction between learners enables scaffolding and cognitive co-construction, but primarily in cases in which processing can be communicated and observed.

When and for whom does it work?

Empirical evidence from health professions education

In this section, we review how the empirical evidence from health professions education supports or contradicts the hypotheses we have outlined. Recent studies have provided insight into the type of interaction that takes place between learners during the collaborative learning of clinical skills and into the relative effectiveness of this learning format compared with individual practice (Table 1).

The hypotheses related to the social interaction perspective (hypotheses 1 and 2) are supported by recent studies involving dyad practice. In a study conducted by Räder *et al.*, working with another novice was found to give learners a sense of security and prompted self-disclosure in performance and

Table 1 Overview of randomised controlled trials examining the effectiveness of collaborative skills learning in health professions education

Study	Task	Participants	Intervention versus control	Type of test	Study outcome
Rogers *et al.* (2000)[34]	Computer-assisted learning of surgical knot tying (45 minutes)	Novice medical students	Dyad versus individual practice	Pre- and post-tests	Inferiority of dyad group compared with singles group
Walsh *et al.* (2011)[31]	Urinary catheterisation (three trials)	Novice medical and nursing students	Dyad versus computer-assisted versus expert-assisted learning	Post- and 1-week retention tests	Dyad group inferiority
Grierson *et al.* (2012)[35]	Ventrogluteal injection simulation	Novice nursing students	Observation practice with expert feedback versus observation practice with self-assessment and expert feedback versus observational practice with peer feedback and expert, self-assessment feedback	14-day retention and transfer test	Peer feedback for observational practice superior to other groups
Tolsgaard *et al.* (2013)[3]	Patient encounter management (4 hours)	Novice medical students	Dyad versus individual practice	2-week retention test	Dyad group superiority
Shanks *et al.* (2013)[29]	Simulation-based lumbar puncture training (24 minutes)	First-year internal medicine residents	Dyad versus individual practice	Pre-, post- and 6-week retention tests	Greater pre–post-test gains for dyad group but equivalent retention test performances
Räder *et al.* (2014)[26]	Simulation-based coronary angiography training (3.5 hours)	Final-year medical students	Dyad versus individual practice	2-week retention test	No significant differences in performance
Bjerrum *et al.* (2014)[30]	Simulation-based bronchoscopy training (10 trials)	Novice medical students	Dyad versus individual practice	Pre-, post, and 2-week retention tests	No significant differences found
Tolsgaard *et al.* (2015)[28]	Simulation-based ultrasound training (2 hours)	Final-year medical students	Dyad versus individual practice	Pre-, post- and transfer tests	Non-inferiority of dyad group transfer test performances

communication.[26] Moreover, the social component of collaboration seemed to positively affect learner motivation and encouragement.[26] In line with these findings, Tolsgaard *et al.*[27] reported positive effects of the collaborative learning of clinical skills on learners' self-efficacy and confidence.[3] Consistent with social interdependence theory (hypothesis 1), learners perceived malfunctioning collaboration and poor social dynamics as potentially detrimental to learning.[26,27] However, in relation to this perspective, it is noteworthy that dyad participants had no influence on their choice of partner in the studies demonstrating learning outcomes that were superior or equivalent to those of individual learning.[3,26,28–30] A mix of social interactions and dynamics may therefore be expected in these dyads. Hence, the quality of the social interaction may influence learners' perceptions of the collaboration effects without being directly related to actual learning. Moreover, there is evidence that the quality of interaction between learners does not alone sufficiently ensure learning for novices. In a study involving urinary catheterisation, peer-assisted learning without any extrinsic feedback was inferior to computer-assisted learning and expert-assisted learning.[31] Hence, some level of guidance, prior knowledge[29] or external feedback, such as automated simulator-generated feedback,[28] may be necessary for learning to take place. This is consistent with studies on the learning of fundamental concepts or knowledge domains in which peer-assisted learning is most efficacious when peer assistance is provided by near-peer tutors or facilitators.[32,33]

The role of observational learning is supported by learner reactions to collaborative learning of clinical skills (hypotheses 1 and 3). During simulation-based coronary angiography training, observing the performances and errors of others stimulated learners' reflections on action and contributed to their planning of their own performance. Moreover, the observation of another's performance prompted learners to picture themselves completing the procedure.[26] These internal representations of actions during the observation of other learners' performances support the action imitation and understanding hypothesis (hypothesis 3). However, in another study, learners expressed concerns about the implication of reduced hands-on practice time during later stages of training, although they generally appreciated practising in pairs during initial training.[27] The implications of reduced hands-on practice time in later stages of learning have not been established as existing studies primarily involve learners who were novices to the task being practised. As noted by Tolsgaard *et al.*,[28] the time allocated to dyad practice during simulation-based training seems to be inversely related to immediate gains reflected in performance improvements associated with training. Shanks *et al.*[29] demonstrated greater pre- to post-test gains for dyad participants (24 minutes practice), whereas there were no differences in the studies by Tolsgaard *et al.*[28] (2 hours practice) and Bjerrum *et al.*[30] (maximum 3.3 hours practice), and slightly worse performances in the dyad group in the study by Räder *et al.*[26] (3.5 hours practice). These differences may be explained by the fact that skills become increasingly less difficult with experience. The trade-off between the advantages associated with peer observation and the disadvantages of a reduction in hands-on experience may then become unfavourable for the collaborative learning of clinical skills during advanced stages of skill acquisition. The hypothesis that decreased hands-on practice impairs skills automaticity during later stages of learning is therefore supported by these findings (hypothesis 4).

According to the cognitive perspective hypotheses (hypotheses 5 and 6), the effectiveness of collaborative learning of clinical skills depends on task complexity. However, this hypothesis is not consistently supported by existing studies in health professions education. Positive effects of collaborative learning were demonstrated for a relatively simple skill such as lumbar puncture,[29] whereas collaborative learning during simulation-based coronary angiography training resulted in slightly worse performances, although the difference did not reach statistical significance.[26] As we have suggested, the effects of collaborative learning of clinical skills may be inversely related to time on task, which may also be explained by decreased cognitive load during training (hypothesis 5). Hence, as learners become increasingly experienced, the cognitive load associated with a given task may decrease and so may the benefits of shared cognition. Räder *et al.*[26] found that shared cognition, scaffolding and cognitive co-construction were mediators of learning. Learners also described that collaboration forced them to think aloud, thereby stimulating collaborative and individual reflection on action.[26] When cognitive processes are not observable or communicable, scaffolding and cognitive co-construction may fail. This may be the case in the study by Rogers *et al.*[34] involving collaborative learning during computer-assisted learning, in which collaborative learning led to inferior performances compared with individual learning. One possibility suggested by the cognitive load model is that learners may have had to split their attention between the learning task and the need to manage communication with their peers. These results suggest that collaborative learning adds another source of load to the learning environment in that learners must attend to both the learning materials and manage relationships with their collaborators. Hence, broadening the analysis of collaborative learning to include both the learning task and the interactions within the environment may help to outline how cognitive load can be managed in collaborative learning. In this case, cognitive load theory may be used as a framework for understanding the collaborative learning of clinical skills as the theory would predict that ineffective communication will increase extraneous load rather than decreasing intrinsic load, thereby resulting in impaired learning.

The predictions of the *active–constructive–interactive* continuum theory proposed by Chi[24] seem to be supported by some evidence in medical education (hypothesis 6). For example, Grierson *et al.*[35] examined methods of optimising observation practice by manipulating the levels of collaborative feedback to which students were exposed after simulation-based testing for ventrogluteal injection techniques. The authors created three conditions roughly analogous to the spectrum described by Chi[24] so that their active learning condition included only expert feedback, their constructive condition allowed students to self-assess performance and then to receive expert feedback as an external benchmark, and their interactive condition allowed learners to give feedback to each other in addition to self-assessment and expert feedback. The interactive peer feedback group achieved the highest level of performance at the post-test and reported the highest gains in comparison with baseline testing.[35] Additionally, this group had the highest transfer performance. Albeit that this study focused on optimising two aspects of collaborative learning taken from motor skills theory (observation and feedback), it suggests that a judicious mix of collaborative and expert or self-guided learning provides benefits additional to the use of only one strategy.[31] However, further exploration of the unique learning interactions in collaborative environments and their relationships to learning outcomes is still needed.[36]

Based on the hypotheses supported in the medical education literature, we developed a mid-level theoretical model of the effectiveness of collaborative learning of clinical skills (Fig. 1). Mid-level theories are made of relatively concrete concepts that can be empirically tested.[37] In this model, we adopted the notion that the effectiveness of collaborative learning of clinical skills decreases with time on task and that learning outcomes are affected by several factors. Factors that may affect learning positively include improved self-efficacy and confidence, and the benefits derived from observation, cognitive co-construction and scaffolding. By contrast, reductions in hands-on experience, as well as task processing that cannot be observed or communicated, may impair the effects of collaborative learning of clinical skills.[6]

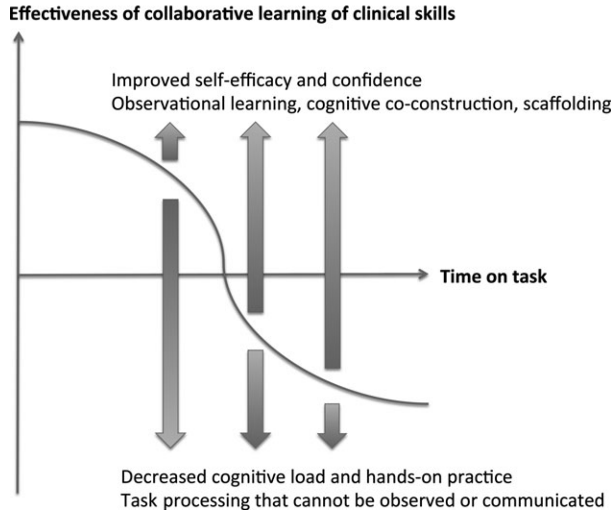

Figure 1 A model for the effectiveness of collaborative learning of clinical skills in health professions education. Collaborative learning of clinical skills is effective during early skills acquisition when cognitive load is high. With practice, the cognitive load decreases and the costs of communication and reductions in hands-on time make collaborative learning increasingly ineffective. The arrows indicate factors that may enhance or impair the overall effect of collaborative learning of clinical skills.

CONCLUSIONS

Existing studies on the collaborative learning of clinical skills in health professions education have been conducted in simulated settings using simulated patients, virtual reality simulation or computer-assisted learning. However, little is known about how collaborative learning of clinical skills may work in the clinical setting, where social dynamics are changed and opportunities for repeated practice do not always occur. Future research may therefore consider if and how collaborative learning of clinical skills may be used to improve learning in the clinical setting. The social dynamics may be changed by the feedback provided by peers, but we know little of the extent to which social dynamics and the formation of relationships modify the usefulness and reception of feedback. Studies of student learning in workplace settings such as clerkship training suggest that the forming of relationships with others[38] represents a critical mechanism for learning. Further exploration of the social factors that influence training in collaborative skills is likely to be warranted. Moreover, the difference in outcomes in learners working with same-level learners and those working with a more advanced peer is yet to be explored in skills training. Recent studies indicate that observation of the progressive learning of a task rather than a model task performance is important for the observer's implicit engagement of neural systems for movement strategies.[39] This implies an advantage in same-level learners, but its significance has not been established in the context of medical education. However, research in concept learning in medical education also reports strong benefits of near-peer learning,[40] although further clarification in this domain is also required. The present paper has focused mainly on skill learning in the individual, but the role of interprofessional collaboration in learning is a subject for future research. Finally, from the motor learning perspective, studies that explore how collaborative learning affects the development of skills automaticity are required. Given the breadth of possible learning interactions fostered by collaborative learning, explorative and experimental studies to clarify enabling conditions and critical mechanisms remain necessary if the field is to advance.

In summary, the collaborative learning of clinical skills is supported by theories that can be categorised according to a social interaction perspective, a motor skills learning perspective, and a cognitive perspective. Collaborative learning of clinical skills leads to improvements in self-efficacy, confidence and performance when task processing is observable or communicable. However, the effects of the collaborative learning of clinical skills may decrease over time as the benefits derived from shared cognition, scaffolding and cognitive co-construction are outweighed by the disadvantages imposed by reductions in hands-on experience and time on task.

Contributors: all authors contributed to the conception and design of the study. MGT wrote the first draft and KMK and CVR revised it critically. All authors approved the final and submitted version of the manuscript. All authors are accountable for all aspects of the work.
Acknowledgements: none.
Funding: this study was funded in part by a grant from the Laerdal Foundation.
Conflicts of interest: none.
Ethical approval: not applicable.

REFERENCES

1 Dillenbourg P. *Collaborative Learning: Cognitive and Computational Approaches*. Oxford: Elsevier 1999.
2 National Health Service Education for Scotland. Partnerships for care: taking forward the Scottish clinical skills strategy. 2007. http://www.csmen.scot.nhs.uk/media/1867/scottish_clinical_skills_strategy_exec_summary.pdf. [Accessed 10 August 2015.]
3 Tolsgaard MG, Bjørck S, Rasmussen MB, Gustafsson A, Ringsted C. Improving efficiency of clinical skills training: a randomised trial. *J Gen Intern Med* 2013;**28**:1072–7.
4 Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ* 2010;**44**(1):75–84.
5 Parmelee D, Michaelsen LK, Cook S, Hudes PD. Team-based learning: a practical guide. AMEE Guide No. 65. *Med Teach* 2012;**34**:e275–87.
6 Crook AE, Bier ME. When training with a partner is inferior to training alone: the importance of dyad type and interaction quality. *J Exp Psychol Appl* 2010;**16**:335–48.
7 Stahl G. Theories of cognition in collaborative learning. In: Hmelo-Silver C, Chinn C, Chan C, O'Donnell A, eds. *The International Handbook of Collaborative Learning*. New York, NY: Routledge 2013;**4**:74–90.
8 Johnson DW, Johnson RT. An educational psychology success story: social interdependence theory and cooperative learning. *Educ Res* 2009;**36**:365–79.
9 Vygotsky LS. *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press 1978.
10 Piaget J. *The Equilibration of Cognitive Structures: The Central Problem of Intellectual Development*. Chicago, IL: University of Chicago Press 1985.
11 Bandura A. *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall 1986.
12 Nichols JD, Miller RB. Cooperative learning and student motivation. *Contemp Educ Psychol* 1994;**19**:167–78.
13 Slavin RE. Instruction based on cooperative learning. In: Mayer R, Alexander P, eds. *Handbook of Research on Learning and Instruction*. New York, NY: Routledge 2011;322–43.
14 Kerr N. Motivational gains in performance groups: aspects and prospects. In: Fargas J, Williams K, Wheeler L, eds. *The Social Mind: Cognitive and Motivational Aspects of Interpersonal Behavior*. New York, NY: Cambridge University Press 2001;350–70.
15 Deutsch M. A theory of cooperation and competition. *Hum Rel* 1949;**2**:129–52.
16 Shebilske WL, Regian JW, Arthur W, Jordan JA. A dyadic protocol for training complex skills. *Hum Factors* 1992;**34**:369–74.
17 Shea CH, Wulf G, Whitacre C. Enhancing training efficiency and effectiveness through the use of dyad training. *J Motor Behav* 1999;**31**:119–25.
18 Granados C, Wulf G. Enhancing motor learning through dyad practice: contributions of observation and dialogue. *Res Q Exerc Sport* 2007;**78**:197–203.
19 Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci* 2004;**27**:169–92.
20 Shiffrin RM, Schneider W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychol Rev* 1977;**84**:127–90.
21 Sweller J. Cognitive load during problem solving. *Cogn Sci* 1988;**12**:257–85.
22 Janssen J, Kirschner F, Erkens G, Kirschner PA, Paas F. Making the black box of collaborative learning transparent: combining process-oriented and cognitive lead approaches. *Educ Psychol Rev* 2010;**22**:139–54.

23 Kirschner F, Paas F, Kirschner PA. A cognitive load approach to collaborative learning: united brains for complex tasks. *Educ Psychol Rev* 2009;**21**:31–42.

24 Chi THM. Active–constructive–interactive: a conceptual framework for differentiating learning activities. *Top Cogn Sci* 2009;**1**:73–105.

25 Goldin-Meadow S, Beilock S. Action's influence on thought: the case of gesture. *Perspect Psychol Sci* 2010;**7** (5):664–74.

26 Räder SB, Henriksen A-H, Butrymovich V, Sander M, Jørgensen E, Lönn L, Ringsted CV. A comparison of the effect of dyad practice versus that of individual practice on simulation-based complex skills learning. *Acad Med* 2014;**89**:1287–94.

27 Tolsgaard MG, Rasmussen MB, Bjørck S, Gustafsson A, Ringsted CV. Medical students' perception of dyad practice. *Perspect Med Educ* 2014;**3**:500–7.

28 Tolsgaard MG, Madsen ME, Ringsted C, Oxlund BS, Oldenburg A, Sorensen JL, Ottesen B, Tabor A. The effect of dyad versus individual simulation-based ultrasound training on skills transfer. *Med Educ* 2015;**49**(3):286–95.

29 Shanks D, Brydges R, den Brok W, Nair P, Hatala R. Are two heads better than one? Comparing dyad and self-regulated learning in simulation training. *Med Educ* 2013;**47**(12):1215–22.

30 Bjerrum AS, Eika B, Charles P, Hilberg O. Dyad practice is efficient practice: a randomised bronchoscopy simulation study. *Med Educ* 2014;**48**(7):705–12.

31 Walsh CM, Rose DN, Dubrowski A, Ling SC, Grierson LE, Backstein D, Carnahan H. Learning in the simulated setting: a comparison of expert-, peer-, and computer-assisted learning. *Acad Med* 2011;**86**:12–6.

32 Reiter HI, Rosenfeld J, Nandagopal K, Eva KW. Do clinical clerks provide candidates with adequate formative assessment during objective structured clinical examinations? *Adv Health Sci Educ Theory Pract* 2004;**9**:189–99.

33 Perera J, Mohamadou G, Kaur S. The use of objective structured self-assessment and peer-feedback (OSSP) for learning communication skills: evaluation using a controlled trial. *Adv Health Sci Educ Theory Pract* 2010;**15**:185–93.

34 Rogers DA, Regehr G, Gelula M, Yeh KA, Howdieshell TR, Webb W. Peer teaching and computer-assisted learning: an effective combination for surgical skill training? *J Surg Res* 2000;**92**:53–5.

35 Grierson LEM, Barry M, Kapralos B, Carnahan H, Dubrowski A. The role of collaborative interactivity in the observational practice of clinical skills. *Med Educ* 2012;**46**(4):409–16.

36 Rojas D, Cheung JJ, Weber B, Kapralos B, Carnahan H, Bägli DJ, Dubrowski A. An online practice and educational networking system for technical skills: learning experience in expert facilitated vs. independent learning communities. *Stud Health Technol Inform* 2012;**173**:393–7.

37 Merton RK. *Social Theory and Social Structure*. New York, NY: Free Press 1968.

38 Han H, Roberts NK, Korte R. Learning in the real place: medical students' learning and socialisation in clerkships at one medical school. *Acad Med* 2015;**90**:231–9.

39 Mattar AAG, Gribble PL. Motor learning by observing. *Neuron* 2005;**46**:153–80.

40 Burgess A, McGregor D, Mellis C. Medical students as peer tutors: a systematic review. *BMC Med Educ* 2014;**14**:115.

Received 15 February 2015; editorial comments to author 23 April 2015, accepted for publication 16 June 2015

