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REVIEW ARTICLE

Approaches to Teaching Medical Procedural Skills: A Scoping Review

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ABSTRACT:
Background. Current approaches to teaching medical procedural skills were developed over 70 years ago. Developments in teaching, movement control, motor learning, educational technology, and understanding of human cognition need to be integrated into the contemporary teaching of medical procedural skills.
Objective. This scoping review analyses approaches to developing motor skills and examines the key elements supporting contemporary medical procedural skills training.
Design. The PRISMA-ScR extension was employed in this review. The methodology had twenty applicable items. The databases used were PubMed, ERIC, PsycINFO, CINAHL, SPORTdiscus, ProQuest Education database, A+Education, Scopus and Web of Science to identify papers and texts published between 1980 and 2023 related to frameworks for teaching medical psychomotor tasks, motor skills, and motor learning to inform approaches to developing medical procedural skills. Data were extracted independently by each of the two researchers, using a standardised form.
Results. Three main framework models were identified. An early model, a 'see one, do one, teach one' mentoring model, was recognised. The cognitive-based representative model gained popularity for medical procedural skill development in the 1990s and persists in simulation-based training. Most biomedical publications promote a cognitive representative model of skill development. The non-medical domains propose an ecological model of movements leading to a constraint-led approach. There is a lack of experimental evidence to support the effectiveness of these frameworks.
Conclusions. While medical education trains with a cognitive-based representative model, other domains have successfully evolved to a constraint-led approach. Further investigation into the applicability and evaluation of ecological models in medical procedural skills development is needed.
Scoping review registration: This protocol has been registered with the Open Science Framework.
Keywords: Procedural skills, mentoring, representative model, constraint-led approach

Introduction

The advances in healthcare over the past century have significantly improved the lives of patients and reduced suffering. Many new medical procedures have reduced morbidity and allowed rapid recovery. The developments have challenged medical educators in teaching these psychomotor procedures. The medical education literature needs a broad overview of the approaches to teaching medical procedures that incorporate advances in training in other domains. Examining such approaches may provide solutions for teachers to gain efficiency and effectiveness in training.

RATIONALE

Procedures in healthcare are vital and range from the simple drawing up of a drug from a vial into a syringe to complex diagnostic and therapeutic tasks such as echocardiography, laparoscopic surgery, neurosurgery, and airway management. Most healthcare disciplines require extensive and complex psychomotor skills acquired over a long training period and adapted with experience and deliberation. [1] In Australia, in 2017–18, there were 11.3 million separations (episodes of admitted patient care) in Australia's public and private hospitals. Between 2013–14 and 2017–18, separations rose by 3.8% each year. This was greater than the average growth in population over the same period (1.6% per year). [2] There has also been a significant increase in the number of new procedural tasks performed. The new procedures are more complex, incorporating new technologies. This has increased the demand for training in medical procedural tasks and the need for specific training.

Rapidly changing medical technology and the availability of new complex diagnostic and therapeutic equipment have revolutionised how health care is delivered. [3] The public expects procedure performance at an expert level. It is estimated that the doubling time of medical knowledge in 1950 was 50 years; in 1980, 7 years; in 2010, 3.5 years; and is currently seven months. [4] Teaching medical students and practitioners the cognitive and procedural elements require growing training efficiency and effectiveness. [4]

Motor control theories provide a framework for interpreting how learning movements and motor skills occur. In the early 1900s, movements were thought to occur through motor reflex linkages. [5] Since the middle of the twentieth century, new concepts of movements have evolved to include systems models and dynamic systems theory. [5] Concepts in cognition have also developed and are currently considered embedded, enacted, embodied, and extended. [6] These concepts should form the basis of current medical procedural skill development approaches.

New teaching techniques, including videos, high-fidelity simulation, virtual reality, and online courses, challenge the framework of procedural skill training developed before the technology. [7]

Technical errors in the performance of procedures are known to produce morbidity and mortality. In a study analysing closed surgical malpractice claims, 52%(n 133) of cases of technical errors were detected among 258 claims in which death or permanent injuries occurred. [8] Many technical errors occur in patients with abnormal size, anatomy, or environmental conditions. [9] These errors point to deficiencies in the adaptation to patient variability and alternate environmental conditions. Technical skills also vary among practitioners. [10]

OBJECTIVES

The primary objective was to map the existing literature for existing knowledge and directives for teaching motor skills in medicine, identify the theoretical basis, and elicit existing gaps in knowledge and the application of contemporary theory. The research questions formulated are:

(a) What are the current approaches to teaching motor skills based on contemporary motor learning theory?

(b) What motor learning elements from contemporary motor learning theory and human movement theory can be used to generate an approach or conceptual framework for procedural skills teaching?

This scoping review aims to study the current training approaches and frameworks for developing medical procedural skills to suit present and future needs.

Methods

We conducted a scoping review to understand the extent, range (variety), and nature of the teaching approaches used, the evidence presented and a comparison between the frameworks. [11]

PROTOCOL AND REGISTRATION

The JBI methodology, the PRISMA scoping review extension, and the checklist framed this scoping review and its reporting. [11,12] It was guided by a professional librarian (L.E.) for search strategy, keyword generation, search strings, and study selection in May 2023.

ELIGIBILITY CRITERIA

The manuscripts included in the review needed to address or provide an approach or framework for teaching or developing motor skills or tasks. Papers comparing training approaches or providing experimental evidence of an approach were included. The review also sought information addressing concepts of procedural skill teaching, movement theory, skill acquisition theory, and motor learning theory, forming the framework's foundation. Peer-reviewed texts from journals, textbooks, and electronic publications were accepted. The contexts for motor skill training included medicine, healthcare, sports, physical exercise, and rehabilitation. The review included all full-text available literature in English from resources published between 1980 and 2023. Backward chaining of references from published material was sought when the manuscript supported the concepts regarding teaching approaches.

Articles were excluded if they addressed motor development in children, post-injury, stroke rehabilitation, or disease processes, including Parkinson's disease or dementia.

INFORMATION SOURCES

The following databases were searched: PubMed, ERIC, PsycINFO, CINAHL, SPORTdiscus, ProQuest Education database, A+Education, Scopus, and Web of Science. The grey literature, which included printed textbooks, blogs, and electronic media, was searched using Google Scholar and the Google search engine.

SEARCH

An initial search strategy, including keywords and MeSH, was conducted for the PubMed database. This was modified and adapted for other databases to generate the final search for the various databases. The search strings are included in the appendix. The search results were exported into the Covidence software package (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at www.covidence.org), and duplicates were removed from the software.

SELECTION OF SOURCES OF EVIDENCE

Two authors (KT and LE) performed the title and abstract screening over four weeks. Conflicts at the initial screening stage were discussed over four meetings to provide the final selection for a full-text review. The full-text reviews were conducted over six weeks for further elimination and selection. Decisions regarding the final accepted texts were discussed between KT and LE. A second reading of the selected full texts was conducted, and the texts were grouped into a selected articles folder stored electronically. The final framework texts and supporting evidence texts were chosen for the third reading of the articles. KT and AvZ reviewed the framework texts to produce a final list for data extraction.

DATA CHARTING PROCESS

The full text of each article selected for the review was initially stored electronically in a folder. Later, it was sorted into framework text and supporting text folders.

DATA ITEMS

We extracted data on the characteristics of the article, including the focus of approach, year of publication, and orientation (medical, general practice, dermatology, and sports). The keywords, MeSH items, and the stated goals of the article were captured when presented. The primary data items extracted were the critical points of the framework or structure of teaching, and supporting experimental were extracted. Specifically, literature based on contemporary motor learning or human movement theory was noted as part of the extraction.

CRITICAL APPRAISAL OF INDIVIDUAL SOURCES

As the sources of information were from disparate domains and types of publications and were qualitative, a critical appraisal of individual sources was not conducted.

SYNTHESIS OF RESULTS (METHODS)

We grouped the selected framework texts into an overview of the approach and placed them in a timeline. The selected texts were grouped by their domain (medical, sports, or other), date of publication, stated goals, key points of the framework promoted, and evidence provided for the framework. The orientation of the framework proposed was analysed and grouped into broad categories.

Articles supporting a framework with experimental evidence or comparing frameworks were retained in a separate folder for discussion.

The results were entered into tables on the training approach and motor learning elements presented.

Results

SELECTION OF SOURCES OF EVIDENCE

The literature search revealed a total of 5925 studies. The studies were exported to Covidence. Four items were included from citation searching (two) and grey literature (two). After removing 1,895 duplicates, identified by software and manually, 4,030 studies were screened based on title and abstract. Of these, 391 were chosen for full-text review after exclusion criteria were applied. Eleven of the articles could not be retrieved. The full-text examination revealed 111 potentially relevant articles for inclusion. The remaining 30 articles were considered eligible for the review as they directly related to a teaching approach or developing a motor skills approach or framework. (Figure 1)

CHARACTERISTICS OF SOURCES OF EVIDENCE

There were two articles on the 'see one, do one, teach one' approach [13,14] and fifteen manuscripts related to the cognitive-based representative framework. [15-29] We selected nine manuscripts applying a constraint-led approach after eliminating other articles referring to the classical subject descriptions in the foundation textbooks. [30-38] Four other descriptions of new or innovative methods in the medical literature were also included. [39-42] The data items are collated in Table 1. The manuscripts were scrutinised for experimental evidence provided and if the theories of skill acquisition, motor control, and movement theory supported them. This data is presented in Table 2.

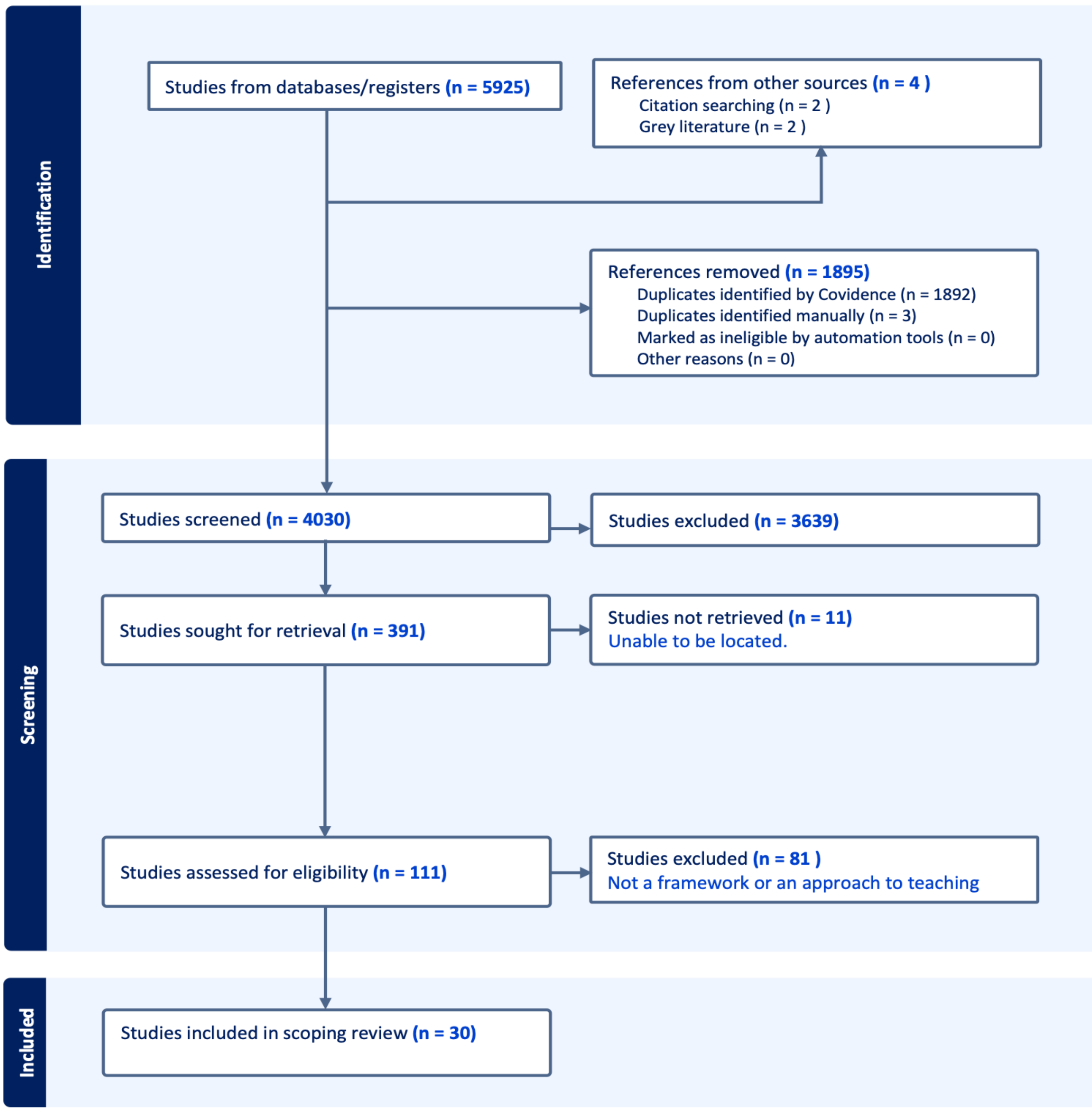

Figure 1: PRISMA sequential process of identifying the studies included in the analysis flowchart

Table 1: General characteristics of selected studies describing a skills training approach

APPROACH	Year First, Author, Reference	Orientation	Key Words MeSH	Stated Goals	Experimental evidence	Key points of framework	Overview
Teaching Procedural Skills	1997 Norris [13]	Medical	Nil	'Teaching basic procedures'	No	Demonstration by immediate senior	See one, do one, teach one with test for competency
Understanding cognitive aspects of procedure. "Hands-on" component	2011 Birnbaumer [14]	Medical	Nil	'...an approach to teaching both the cognitive and the manual skills necessary to perform procedures'	No	Need to learn cognitive component first. Demonstration visualises steps Teaching ensures cognitive and manual steps are combined	See one, do one, teach one **FRAMEWORK**
Linking psychomotor domain theory to procedural medicine	1997 Kovacs [15]	Medical – Emergency Medicine	Emergency medicine; medical education; skills; procedures; technical skills; psychomotor skills	'…we should have an understanding of educational issues relevant to psychomotor skills'	No	Adam's closed-loop theory Simpson's taxonomy	Learn, See, Practice, Do. Competence Cognitive and motor phases separated
Need for GP supervisors to teach procedures	2003 Fraser [16]	Medical General Practice	Nil	'…develop a framework for teaching and assessing procedural skills and their assessment in general practice'	No	Demonstrate, deconstruct, comprehend, perform	Peyton & Walker approach Assessment of learning
Education Theory-Based Method	2004 Wang [17]	Medical Dermatology	Nil	'To determine the effectiveness of an education theory–based method to teach students to place and tie a simple interrupted stitch'	Yes	Demonstrate, deconstruct, comprehend, perform	Peyton & Walker approach
Teaching complex procedures	2008 Grantcharov [18]	Medical	Nil	'…to provide an evidence-based algorithm for procedural skills training'	No	Pre-patient training- cognitive knowledge, Clinical training on patient – demonstrate, deconstruct, comprehend, perform part task. Perform whole task	Cognitive representative approach using Peyton & Walker approach. (see one, do one, teach one no longer relevant)
Competency-Based medical education	2010 Swing [19]	Medical	Nil	'…explore CBME from the perspective of the learning sciences.'	No	Cognitive component learned before motor. Proceed from simple tasks to complex ones. Practice variation is needed. Role of motivation in learning	Learn Observe exemplars Focused practice Immediate feedback Meaningful and diverse settings Reflect on performance

APPROACH	Year First, Author, Reference	Orientation	Key Words MeSH	Stated Goals	Experimental evidence	Key points of framework	Overview
General Practitioners have responsibility for facilitating core skills learning	2011 Wearne [20]	General Practice	General Practice; teaching; diagnostic techniques and procedures; clinical competence; therapeutic techniques and procedures	'…summarise how procedural skills are learned and describes a practical framework for constructing a supportive learning environment that is safe for patients and learners'	No	Demonstration, deconstruction, comprehension, performance	Peyton & Walker approach Aim to 'fix' the skill (see one, do one, teach one historical)
Gagne' Approach	2013 Buscombe [21]	Medical	Nil	'…consider how Robert Gagne's instructional design model may be effectively used to design lesson plans and teach procedural skills'	No	Gain attention Motivate Learning objectives Stimulate recall of prior learning Stimulate Learning guidance Perform Feedback Assess	Sequential approach
Review based framework	2015 Sawyer [22]	Medical	Nil	'…describe an evidence-based, pedagogical framework for teaching procedural skills in medicine.'	No	Learn See Practice Prove Do Maintain	Cognitive representative approach using Peyton & Walker approach. **FRAMEWORK**
Teaching in busy office environments	2016 Garcia-Rodriguez [23]	Medical Family physicians	Nil	'…provide specific tips and resources that can be used by family physicians in any environment during daily teaching of procedures'	No	Learn See Practice Prove Do Maintain Cognitive component, feedback, assessment	Cognitive representative approach using Peyton & Walker approach. Assessment

APPROACH	Year First, Author, Reference	Orientation	Key Words MeSH	Stated Goals	Experimental evidence	Key points of framework	Overview
Nursing procedures	2016 Oermann [24]	Nursing	Nil	'…explore psychomotor skill learning in nursing and the need for practice of skills, and to suggest strategies for nurse educators in both nursing programs and clinical settings for teaching motor and procedural skills.'	No	Three phases of learning- Cognitive, Associative, Autonomous. Framework- Explain skill Demonstrate Deliberate practice Assess performance Continued practice	Cognitive representative approach using Peyton & Walker approach. Assessment Rapid Cycle Deliberate Practice
Conscious Competence model	2018 Ojevwe [25]	Medical	Nil	'…present a theoretical framework for teaching procedural skills to trainees'	No	Equip learners to understand a procedure, Expose learners to procedure, Enable learners to practice, Evaluate competency	Cognitive representative approach using Peyton & Walker approach. Assessment
Teaching procedural skills	2020 Burgess [26]	Medical	Procedural skills teaching; Peyton's four-step approach; determining competency; provision of feedback; deliberate practice.	'…to explore how skills are learned; ways to improve skills performance; determining competency; and the provision of effective feedback.'	No	Knowledge, communication, performance. Include fundamentals Demonstration Integrate theory with practice Break skills down into steps Provide feedback	Use Peyton & Walker method Use Sawyer framework
Simulation based procedural skills teaching	2021 Coro-Montanet [27]	Dentistry	Task simulator; procedural skills training; psychomotor domain	'…we designed a protocol for conducting training workshops that develop complex psychomotor skills'	No	Briefing Skill development Feeds- Teach theory knowledge Repeated practice – Objective checklist & feedback Evaluate	Cognitive approach with Simpson's taxonomy
Conscious competence model	2012 Manthey [28]	Medical	Nil	'…a novel approach that divides procedural education into a four-step process that covers knowledge, experience, technical skill development and competency evaluation.'	No	Learn knowledge of task Exposure by observation and participation Skill acquisition by practice Assess - summative	Stepwise learning

APPROACH	Year First, Author, Reference	Orientation	Key Words MeSH	Stated Goals	Experimental evidence	Key points of framework	Overview
Microskills	2010 Razavi [29]	Medical	Clinical skills centre; microskills; perceived ability; self-assessment; self-scoring stationed training	'…we propose a stationed-based deconstructed training model for tuition of each microskill'	Yes.	Deconstruct complex skill into simple microskills. Presentation. Demonstration. deconstruction, practice Perform main skill	Use Peyton & Walker method With part-task teaching
Sports Science	1994 Davids [30]	Sports	Complex systems; interdisciplinarity ; perception-action coupling	'…examines the viability of the natural physical alternative to traditional cognitive modelling of the sport performer.'	No	Cognitive school uses computer analogue. Change to natural physical group for motor control and movement variability.	Change from mental representational model.
Ecological Dynamics	2013 Davids [31]	Sports	Ecological dynamics; representative design; skill acquisition; talent development	'…how ecological dynamics, a theory focusing on the performer-environment relationship, provides a basis for understanding skill. acquisition in sport.'	No	Intentions, perceptions and actions are intertwined. Sample information from performance environment	Ecological dynamics forms basis of skill acquisition in sport.
Movement based	2010 Brymer [32]	Sports	Nil	'…introduces the constraints-led approach to skills acquisition.'	No	Perception and action linked by affordances. Manipulate constraints to facilitate learning. Representative learning design	Constraints-led approach (CLA)
Constraint-led	2010 Renshaw [33]	Sports	Nonlinear pedagogy; constraints; movement skills; game play; learning	'…we overview the motor learning approach emanating from the constraints-led perspective, and examine how it can substantiate a platform for a new pedagogical framework in physical education: nonlinear pedagogy.'	Yes, Rugby players	Manipulate constraints – task, performer, environment for affordance. Representative practice task design. Repetition without repetition.	Constraints-led approach (CLA)
Motor Learning	2014 Coker [34]	Sports	Nil	'… to offer practitioners an error correction framework… derived from constraints led approach.'	No	Constraint manipulation. Shape movement patterns	Constraints-led approach (CLA)
Skills coaching	2019 Renshaw [35]	Sports *Book chapter	Nil	Designing environments	No	Set session intention. Constrain to afford. Representative learning design. Repetition without repetition.	Constraints-led approach (CLA) **FRAMEWORK**

APPROACH	Year First, Author, Reference	Orientation	Key Words MeSH	Stated Goals	Experimental evidence	Key points of framework	Overview
Coaching	2019 Roberts [36]	Sports	Nil	'… to provide a nuanced understanding of the ideas and concepts …of the methodologies of a constraints-led approach (CLA)…'	Yes	Coaches as environmental architects. Importance of experiential knowledge. Information regulates actions. Importance of representative design. Encourage self-organisation	Theoretical foundation of CLA-Ecological Dynamics
Tennis	2023 Parry [37]	Sports	Nil	'…to introduce coaches to a more contemporary theoretical framework of skill acquisition that will drive the exploration of new practice methods to maximize skill development across all ages.'	No	Traditional view is mental representations. New approach via ecological dynamics generates a constraint-led perspective.	Constraints-led approach (CLA) Framework Transition from representative model
Nursing	2023 Renden [38]	Nursing	Nil	'… will explore the relevance of the constraints-led approach for nurse education, specifically when teaching nursing skills.'	Yes	Learning is nonlinear. Nonlinear pedagogy. Constraints manipulated for teaching	Constraints-led approach (CLA) Framework
Surgical	2010 Unalan [39]	Orthopaedic arthroscopy	Skill; learning; basic motor skills; bovine knee; evaluation; arthroscopy	'…to introduce, evaluate, and propose a basic arthroscopy training course with interactive methods as using bovine knees, joint models but mainly focusing on practices with motor skill-learning devices.'	Yes	Basic skills taught in six steps. Background definitions. Video presentations, demonstration. Basic motor skill exercises. Practice on models. Practice on bovine knee. Evaluation of skill	Basic motor skills training. Learn by doing. Learn while doing.
Simulation based	2012 Tjiam [40]	Simulation based nephrostomy	Nil	'…an approach to designing simulator-based skill training comprising cognitive task analysis integrated with instructional design according to the four-component/instructional design model.'	No	Use cognitive task analysis. Scenarios increasing levels of difficulty. Supportive information. Just in time 'how-to' information. Part-task practice	Progressive development of skills.
Obstetrics	2023 Stieglitz [41]	Shoulder dystocia	E-learning; medical studies; obstetrics; shoulder dystocia	'…to demonstrate how the learning objectives for shoulder dystocia… can be successfully taught in medical studies using a blended learning concept.'	Yes	E-learning of theory followed by simulation practice	Blended model Representative model
Surgery	2008 Wong [42]	Surgical skills	Education; evaluation; model; surgery; training	' Review of cognitive motor learning for teaching surgical skill…'	No	Training on simulators is transferrable Traditional model of apprenticeship alone is no longer appropriate	Add simulation to training.

Table 2: Motor learning theory elements

APPROACH	Year, First Author, Reference	Orientation	Is Skills acquisition theory considered	Is motor control theory considered	Is movement theory considered	Overview of Approach
Teaching Procedural Skills	1997 Norris [13]	Medical	No	No	No	Imitation
Understanding cognitive aspects of procedure. "Hands-on" component	2011 Birnbaumer [14]	Medical	No	No	No	Imitation
Linking psychomotor domain theory to procedural medicine	1997 Kovacs [15]	Medical – Emergency Medicine	Simpson's taxonomy	No	Adam's closed-loop theory	Mental Representation - Cognitive learning with imitation
Need for GP supervisors to teach procedures	2003 Fraser [16]	Medical General Practice	No	No	No	Mental Representation - Cognitive learning with imitation
Education Theory-Based Method	2004 Wang [17]	Medical Dermatology	No	No	Demonstrate, deconstruct, comprehend, perform	Mental Representation - Cognitive learning with imitation
Teaching complex procedures	2008 Grantcharov [18]	Medical	No	No	No	Mental Representation - Cognitive learning with imitation
Competency-Based medical education	2010 Swing [19]	Medical	Cognitive learning before motor plan	No	Motor plan with parameters	Mental Representation - Cognitive learning with imitation
General Practitioners have responsibility for facilitating core skills learning	2011 Wearne [20]	General Practice	No	No	No	Mental Representation - Cognitive learning with imitation
Gagne' Approach	2013 Buscombe [21]	Medical	No	No	No	Gagne's Sequential approach for cognitive learning with imitation
Review based framework	2015 Sawyer [22]	Medical	Simpson's taxonomy	No	No	Mental Representation - Cognitive learning with imitation
Teaching in busy office environments	2016 Garcia-Rodriguez [23]	Medical Family physicians	No	No	No	Mental Representation - Cognitive learning with imitation

APPROACH	Year, First Author, Reference	Orientation	Is Skills acquisition theory considered	Is motor control theory considered	Is movement theory considered	Overview of Approach
Nursing procedures	2016 Oermann [24]	Nursing	Cognitive, Associative, Autonomous	No	No	Mental Representation - Cognitive learning with imitation
Conscious Competence model	2018 Ojevwe [25]	Medical	Conscious competence stage model	No	No	Mental Representation - Cognitive learning with imitation
Teaching procedural skills	2020 Burgess [26]	Medical	Taxonomy of psychomotor domain Sequenced stepped	No	No	Mental Representation - Cognitive learning with imitation
Simulation based procedural skills teaching	2021 Coro-Montanet [27]	Dentistry	Fitts & Posner – cognitive model. Burch – conscious competence staged model. Dave – taxonomy Peyton –four-step approach Ericcson – deliberate practice	No	No	Cognitive approach in simulation
Conscious competence model	2012 Manthey [28]	Medical	Conscious competence model	No	No	Mental Representation - Cognitive learning with imitation
Microskills	2010 Razavi [29]	Medical	No	No	No	Mental Representation - Cognitive learning with imitation Deconstruction to microskills
Sports Science	1994 Davids [30]	Sports	Natural perception-movement coupling as alternate to cognitive model	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach –
Ecological Dynamics	2013 Davids [31]	Sports	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Movement based	2010 Brymer [32]	Sports	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability

APPROACH	Year, First Author, Reference	Orientation	Is Skills acquisition theory considered	Is motor control theory considered	Is movement theory considered	Overview of Approach
Constraint-led	2010 Renshaw [33]	Sports	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Motor Learning	2014 Coker [34]	Sports	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Skills coaching	2019 Renshaw [35]	Sports *Book chapter	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Coaching	2019 Roberts [36]	Sports	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Tennis	2023 Parry [37]	Sports	Ecological theory building perception-movement coupling. Representative theory inadequate	Distributed in performer-environment complex	Ecological-dynamics	Constraints-led approach – Session intention Representative learning design Constrain to afford Functional variability
Nursing	2023 Renden [38]	Nursing	Ecological theory building perception-movement coupling	Distributed in performer-environment complex	Learning is nonlinear. Nonlinear pedagogy. Constraints manipulated for teaching	Constraints-led approach (CLA) Framework
Surgical	2010 Unalan [39]	Orthopaedic arthroscopy	No	No	No	Basic motor skills training. Learn by doing. Learn while doing.
Simulation based	2012 Tjiam [40]	Simulation based nephrostomy	Nil	No	No	Cognitive task analysis / 4C model
Obstetrics	2023 Stieglitz [41]	Shoulder dystocia	No	No	No	Blended model Representative model

APPROACH	Year, First Author, Reference	Orientation	Is Skills acquisition theory considered	Is motor control theory considered	Is movement theory considered	Overview of Approach
Surgery	2008 Wong [42]	Surgical skills	No	No	No	Simulation based training in initial phase

Discussion

SUMMARY OF EVIDENCE

We reviewed the studies published over the last 44 years. The literature review findings are presented below according to the research questions.

Question 1: *What are the approaches to teaching motor skills based on contemporary motor learning theory?*

Perspectives on the framework for developing motor skills for skilled tasks have evolved over the past 120 years. The earliest method presented was the didactic lecture accompanied by a demonstration. Practising the task was separate from the approach. [13]

The 'see one, do one, teach one' approach was the subject of two selected papers. An immediate senior or a person who has just learned the task teaches a junior learner by demonstration. The learner performs the task with feedback for correction. Competence was tested before independent practice. [13] Teaching the task to a junior improved cognitive and procedural learning and the teacher's performance skills. [14]

Kovacs linked a taxonomy of learning of the psychomotor domain with a closed-loop theory of motor control in the 'learn, see, practice, do' approach for teaching emergency medicine procedures in 1997. [15] Competence testing was essential before treating patients. The task procedure and extensive background knowledge are initially learned in isolation. This is enhanced by viewing a demonstration of the task to generate a mental representation of it and its actions. Practice requires following the steps learned accompanied by feedback correction. The cognitive model of the task was enhanced by the Peyton and Walker's 4-step approach consisting of demonstration, deconstruction, comprehension and performance steps. [43]

Several authors endorsed this approach in general medicine, [16,20] dermatology, [17] and internal medicine. [18] Only one paper provided experimental evidence comparing the method's benefit over no training in placing interrupted sutures. [17] The competency-based medical education (CBME) perspective stressed learning cognitive components before the motor component and endorsed practice variation. [19]

Reviewing procedural skill teaching in medicine enhanced the framework as 'learn, see, practice, prove, do, maintain'. [22] This received support in office-based procedures performed by family physicians. [23] Neither group provided experimental evidence in support of the framework. Peyton and Walker's 4-step approach combined with the 'learn, see, practice, prove, do, maintain' framework was recently promoted for medical procedural skill training. [26]

Nurses also supported the cognitive-based representative framework. [24] Three phases of motor skill learning were described as cognitive, associative, and autonomous as part of the learning theory. [24] Some authors invoked the conscious-competence model of learning to support the representative model. [25,28]

Simulation-based skill teaching used the same taxonomy of the psychomotor domain, generating a model of 'briefing, skill development, and feeds.' The briefing component developed the cognitive representation of the task before practice on the simulator. [27] Another proposal for training consisted of deconstructing complex tasks into simple micro-skills and teaching them first. [29] A cognitive task analysis of the task supports instruction for the cognitive learning component of the mental model. [44,45]

Healthcare focuses on learning cognitive components before practice. The theoretical basis of this method is not presented or discussed in most publications. The evidence that supports the technique compares teaching with the approach to no teaching. No evidence was presented related to how the skill is acquired, why the movements need to be imitated, the role of experience, and whether the cognitive elements may need to be revised with practice. The cognitive-based representational approach needs to provide evidence of how movements are generated.

In contrast to healthcare, the sports domain has evolved from the cognitive-based representative model of understanding motor skills based on developments in psychology regarding motor control, movement theory, and theories of skill acquisition. The concept of the brain as a computer analogue with motor plans was abandoned in the last decade of the 20th century. [30] Developments in understanding goal-directed movements generated a new framework for motor skills development. [31] The constraints-led approach (CLA) based on non-linear pedagogy has replaced the representative outdoor education and sports model. [33] The CLA has also been promulgated to enhance skills and performance, and the principles of CLA are well-established in sports training textbooks. [35,36] Comparing the two approaches favoured the CLA over the representative model in tennis coaching. [37] Recently, CLA was introduced to nursing skills

training, with benefits showing clinical performance without errors. [38] Renshaw and Davids et al. present many applications of CLA in various sports. [46] A systemic review found the superiority of the CLA approach in interceptive actions, advocating it as a training method. [47]
Innovative approaches to procedural skills were elicited in the literature search. One model effectively taught arthroscopic knee surgery in a six-step system based on learning by doing rather than a cognitive representation with experimental evidence of effectiveness. [39] Another group proposed teaching nephrostomy after a cognitive task analysis by providing supportive information, just-in-time how-to training, and part-task practice before whole-task practice. They also suggested a progressive increase in case complexity during training. No experimental evidence showing educational benefits was presented. [40]

COMPARISON OF FRAMEWORKS
There is little evidence comparing training approaches in the medical domain. A comparison between video-based versions of the 'see one, do one', and Peyton's 4-step approach for teaching surgical skills was found in favour of the Peyton approach for teaching complex skills and performance immediately after training. [48] A systematic review and meta-analysis based on 14 papers reported Peyton's 4-step approach more effective than the 'see one – do one', team-based, or peer teaching methods. [49] There is some doubt on the utility of stepped models to assist skill acquisition and retention when teaching large and complex tasks. [1]

The CLA was better at skill acquisition than mental representative methods or information processing approaches in the sports domain. [37,50,51]

The review suggests that medical teaching should explore new concepts in psychomotor teaching and compare them with the traditional cognitive approach to gain benefits obtained in the sports domain.

Question 2: *What motor learning elements from contemporary motor learning theory and human movement theory can be used to generate an approach or conceptual framework for procedural skills teaching?*
The 'see one, do one, teach one' approach was based on imitation. Kovacs's 'learn, see, practice, do' framework was based on a taxonomy of the psychomotor domain and a closed-loop theory of movement. [15,26] Subsequent frameworks in the medical environment have persisted with this cognitive-based representative model. The motor learning elements from movement, motor control, and skill acquisition theories are not included. Some innovative models have presented aspects of learning by doing. [29,39]

The CLA is based on ecological aspects of movement theory and motor control, moving away from the cognitive models. [30,31] (Table 2)

To sum up, the teaching approaches used in the medical domain use a cognitive-based mental representation model and do not apply aspects of motor control. The sports domain has moved from this model to an ecological-based approach.

The medical education literature did not focus on how goal-directed movements are achieved, the factors influencing skill acquisition, the need for prescribed movements, what exactly is learned, how it is retained, and how expertise develops. These elements would benefit a broad outlook on teaching and may improve methods based on a different approach. The psychomotor skills of medicine are complex, with interactions between the cognitive, motor, affective, physical limitations, and environmental elements. This suggests that understanding complex systems may be required to further develop medical procedural skills training.

LIMITATIONS
This scoping review has several limitations. Firstly, the possible search terms were narrow due to a need for more specific terminology. Using phrases provided a better focus on the search of the literature than relying on Boolean operators. Secondly, our search represents current literature on this topic. Contemporary literature does not present evidence from experience, relying only on experimental data. Thirdly, the literature is biased against publishing negative evidence (publication bias), and individual papers may also have a bias favouring one approach. Fourthly, caution must be expressed with motor learning literature due to the low replication rates of studies (11-45%). [52] Fifthly, there are limits to the information provided in studies comparing approaches as they are from different time periods, diverse domains, cultural diversity, and teaching practices. Sixthly, the individual domains were limited in their focus on motor skills development, with the medical domain focusing on cognitive aspects, whereas the sports studies focused on ecological aspects. This made comparison between the domains exceedingly difficult. Finally, many factors affect the teaching and learning process. This review did not consider the elements of practice, block teaching, integrated teaching, educational technology, and individual

teachers' expertise, which may influence the search and comparison results.

Conclusion

We used the scoping review method to detect three primary medical procedure teaching and training framework models discussed over the past 40 years. Of the 30 papers selected, 17 presented a cognitive approach, and nine presented the evolved constraint-led approach. Four other approaches in medicine were detected, suggesting further investigation. While medical education trains with a cognitive-based representative model, other domains have successfully evolved to a constraint-led approach. Research should be conducted regarding the applicability of a movement-based model for medical procedural skills development.

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KT provided the concept design, literature searches, review, composition of manuscript, and revisions.
LE helped with the concept design, formulation of research strings, review, and editing of the manuscript.
PB and JL supervised, edited, and revised the manuscript.
AvZ supervised, reviewed, edited, and revised the manuscript.

Appendix

Search strategies by electronic databases

PubMed
((("Reproducibility of Results"[Mesh] OR perform*[tiab] or train*[tiab]) AND (task assess*[ti] OR task analysis[tiab] OR "Task Performance and Analysis"[Mesh] OR "Time and Motion Studies"[Mesh] OR "motion analysis"[tiab] OR "Technique analysis"[tiab]) AND ("motor skills"[tiab] OR "Psychomotor Performance"[mAJR] OR "psychomotor skills" OR "movement"[MeSH Terms] OR movement*[tiab] OR "cognitive*"[tiab] OR "human movement*"[tiab] OR biomechanic*[tiab]) AND ("Education, Medical"[Mesh] OR medical education[tiab] OR medical[ti] OR surgical[ti]))) OR (((("procedural skill training"[ti] OR ((teaching[ti] AND (procedural[ti] OR procedures[ti]) AND skill*))) OR ((("Constraints led"[tiab] OR "Constraint led"[tiab] OR constraints based[tiab]) AND (skill* OR Education* OR train*)))) OR (("education, medical"[MeSH Terms] OR "medical education"[Title/Abstract]) AND ("motor"[Title] AND ("learn*"[Tiab] OR "skill*"[Tiab]))) OR "movement competence"[tiab] OR (teaching[tiab] AND "medical procedure*"[tiab]) OR ((“Motor learning”) AND (ecological OR pedagogy))))

ERIC via ProQuest
(Reproducibility OR perform* OR train*) AND ("task assess*" OR "task analysis" OR "Task Performance and Analysis" OR "Time and Motion Studies" OR "motion analysis" OR "Technique analysis") AND ("motor skills" OR "psychomotor skills" OR movement OR movement* OR cognitive* OR "human movement*" OR biomechanic*) AND ("medical education" OR medical OR surgical) OR ("procedural skill training" OR title(teaching AND procedur* AND skill*) OR (("Constraints led" OR "Constraint led" OR "constraints based") AND (skill* OR Education* OR train*)) OR (((education AND medical) OR "medical education") AND (motor AND (learn* OR skill*))) OR ("movement competence" OR (teaching AND "medical procedure*")))

APA PsycINFO via EBSCOhost
((((TI perform* OR AB perform*) OR (TI train* OR AB train*)) AND ((TI "task assess*") OR (TI "task analysis" OR AB "task analysis") OR (DE "Performance") OR ("Time and Motion Stud*") OR (TI "motion analysis" OR AB "motion analysis") OR (TI "Technique analysis" OR AB "Technique analysis")) AND ((TI "motor skills" OR AB "motor skills") OR DE "Perceptual Motor Processes" OR "psychomotor skills" OR (TI movement* OR AB movement*) OR (TI cognitive* OR AB cognitive*) OR (TI "human movement*" OR AB "human movement*") OR (TI biomechanic* OR AB biomechanic*)) AND ((DE "Medical Education") OR (TI "medical education" OR AB "medical education") OR (TI medical) OR (TI surgical)))) OR (((((TI "procedural skill training") OR (((TI teaching) AND ((TI procedural) OR (TI procedures)) AND skill*))) OR ((((TI "Constraints led" OR AB "Constraints led") OR (TI "Constraint led" OR AB "Constraint led") OR (TI "constraints based" OR AB "constraints based")) AND (skill* OR Education* OR train*)))) OR (((DE "Medical Education") OR (TI "medical education" OR AB "medical education")) AND ((TI motor) AND ((TI learn* OR AB learn*) OR (TI skill* OR AB skill*)))) OR (TI "movement competence" OR AB "movement competence") OR ((TI teaching OR AB teaching OR DE "Skill Learning") AND (TI "medical procedure*" OR AB "medical procedure*")) OR (("Motor learning") AND (ecological OR pedagogy))))

SportDiscus via EBSCOhost
(((TI "perform*" OR AB "perform*") OR (TI "train*" OR AB "train*")) AND (TI "task assess*" OR (TI "task analysis" OR AB "task analysis") OR DE "PERFORMANCE evaluation" OR "Time and Motion Studies" OR (TI "motion analysis" OR AB "motion analysis") OR (TI "Technique analysis" OR AB "Technique analysis")) AND ((TI "motor skills" OR AB "motor skills") OR DE "PSYCHOLOGY of movement" OR "Psychomotor Performance" OR "psychomotor skills" OR DE "HUMAN mechanics" OR (TI "movement*" OR AB "movement*") OR (TI "cognitive*" OR AB "cognitive*") OR (TI "human movement*" OR AB "human movement*") OR (TI "biomechanic*" OR AB "biomechanic*")) AND (DE "MEDICINE" OR (TI "medical education" OR AB "medical education") OR TI "medical" OR TI "surgical"))) OR ((((TI "procedural skill training" OR ((TI "teaching" AND (TI "procedural" OR TI "procedures") AND "skill*"))) OR ((“skill acquisition” OR Cognition) AND ecological) OR ((((TI "Constraints led" OR AB "Constraints led") OR (TI "Constraint led" OR AB "Constraint led") OR (TI "constraints based" OR AB "constraints based")) AND ("skill*" OR "Education*" OR "train*")))) OR ((DE "education, medical" OR (TI "medical education" OR AB "medical education")) AND (TI "motor" AND ((TI "learn*" OR AB "learn*") OR (TI "skill*" OR AB "skill*")))) OR (TI "movement competence" OR AB "movement

competence") OR ((TI "teaching" OR AB "teaching") AND (TI "medical procedure*" OR AB "medical procedure*") OR ((DE "MOTOR learning" OR “Motor learning”) AND (ecological OR pedagogy)))

Scopus

(((INDEXTERMS("Reproducibility of Results") OR TITLE-ABS(perform*) OR TITLE-ABS(train*)) AND (TITLE("task assess*") OR TITLE-ABS("task analysis") OR INDEXTERMS("Task Performance and Analysis") OR INDEXTERMS("Time and Motion Studies") OR TITLE-ABS("motion analysis") OR TITLE-ABS("Technique analysis")) AND (TITLE-ABS("motor skills") OR TITLE-ABS("Psychomotor Performance") OR TITLE-ABS("psychomotor skills") OR INDEXTERMS(movement) OR TITLE-ABS(movement*) OR TITLE-ABS(cognitive*) OR TITLE-ABS("human movement*") OR TITLE-ABS(biomechanic*)) AND (INDEXTERMS("Education, Medical") OR TITLE-ABS("medical education") OR TITLE(medical) OR TITLE(surgical)))) OR ((((TITLE("procedural skill training") OR ((TITLE(teaching) AND (TITLE(procedural) OR TITLE(procedures)) AND skill*))) OR (((TITLE-ABS("Constraints led") OR TITLE-ABS("Constraint led") OR TITLE-ABS("constraints based")) AND (skill* OR Education* OR train*)))) OR ((INDEXTERMS("education, medical") OR TITLE-ABS("medical education")) AND (TITLE(motor) AND (TITLE-ABS(learn*) OR TITLE-ABS(skill*)))) OR TITLE-ABS("movement competence") OR (TITLE-ABS(teaching) AND TITLE-ABS("medical procedure*")) OR TITLE-ABS("Motor learning") AND TITLE-ABS(ecological OR pedagogy)))

Web of Science

(TI=perform* OR AB=perform* OR TI=train* OR AB=train*) AND (TI="task assess*" OR TI="task analysis") OR ((TS="Motor learning") AND (TS=ecological OR TS=pedagogy)) OR ((TI=teaching OR AB=teaching) AND (TI="medical procedure*" OR AB="medical procedure*")) OR (TI="movement competence" OR AB="movement competence") OR (TS="education, medical" OR TI="medical education" OR AB="medical education") AND ((TI=motor AND (TI=learn* OR AB=learn* OR TI=skill* OR AB=skill*))) OR (TI="Constraints led" OR AB="Constraints led" OR TI="Constraint led" OR AB="Constraint led" OR TI="constraints based" OR AB="constraints based") AND (TI=skill* OR TI=Education* OR TI=train*) OR (TI="procedural skill training" OR (TI=teaching AND (TI=procedural OR TI=procedures) AND TS=skill*)) OR (TI="Psychomotor Performance" OR TI="psychomotor skills" OR TI=movement* OR TI=cognitive* OR TI="human movement*" OR TI=biomechanic*) AND (TI=medical education OR TI=surgical skill* OR TI=surgical train*) OR (TS="Task Performance and Analysis" OR TS="Time and Motion Studies" OR TI="motion analysis" OR AB="motion analysis" OR TI="Technique analysis" OR AB="Technique analysis") AND (TI="motor skills" OR AB="motor skills")

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