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Pedagogical principles used by anatomy teachers to facilitate the teaching and learning of anatomy to physiotherapy undergraduates in the United Kingdom

Hope Gangata[1] | Katy Vigurs[2]

[1]College of Medicine and Health, University of Exeter, Exeter, UK

[2]School of Education and Social Work, Birmingham City University, Birmingham, UK

Correspondence
Hope Gangata, College of Medicine and Health, College House, University of Exeter, St Luke's Campus, Heavitree Road, Exeter, EX1 2LU, UK.
Email: hopegata@yahoo.co.uk

Abstract

The teaching of anatomy for physiotherapy differs from other health professions, and yet there is lack of guidance for the best practice in the literature, especially within the United Kingdom (UK). The present study aimed to provide the most effective pedagogical guidance for teaching a typical anatomy curriculum for a three-year BSc Physiotherapy degree program within the UK. The research design used a constructivist grounded theory where semi-structured interviews were conducted with eight registered physiotherapists teaching anatomy to undergraduate physiotherapy students within the UK. The study generated 72,292 words of qualitative data that were thematically analyzed using Saldaña's coding techniques until data saturation was reached. The results had three main components: a pedagogical backdrop composed of five pedagogical issues, pedagogical approaches with its three subcomponents and pedagogical timings of phases of when anatomical teaching was conducted across the three undergraduate physiotherapy degree programs. The cognitive load theory (CLT) best explained the results through five main pedagogical principles: spiral curriculum strategies, visual anatomical imagery, kinesthetic anatomical skills, strategies for teaching clinical physiotherapy anatomy, and using anatomical principles for metacognition. The study proposes a new modified version of CLT which acknowledges that newly acquired knowledge is fragile in novice learners, who have limited long-term memory capacities, and subsequently require regular revisitations, and also acknowledges kinesthetic input and germane cognitive load metacognition strategies. The study recommends appointing anatomy theme leads to take responsibility for the spiral curriculum approach across the 3 years and to introduce explicit anatomy teaching during the later clinical years.

KEYWORDS
anatomy teaching, cognitive load theory, physiotherapy, principles, undergraduate

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1 | INTRODUCTION

The knowledge and understanding of anatomy is an integral component of physiotherapy undergraduate training programs within the United Kingdom (UK) (Bithell, 2007). Physiotherapy practice in the UK has expanded in scope to over 28 different specialty networks recognized by the Chartered Society of Physiotherapy (CSP) (CSP-Scope, 2022), and some networks require greater anatomical training, such as postgraduate UK physiotherapists administering musculoskeletal injections (CSP-History, 2022) and requesting radiological imaging for their patients (Bithell, 2007). Anatomy is rated as the most important basic science in medical education (Pabst & Rothkötter, 1997), but is one of the most challenging to learn among medical and biological sciences (Terrell, 2006). In light of the growth in physiotherapy services in the UK and an acknowledgement that anatomical education for physiotherapists requires modernization (Turhan, 2020), there is a need for the development of pedagogical theories to guide subsequent teaching practices. There are very few explicit qualitative pedagogical theories in the literature that guide the teaching and learning of anatomy for physiotherapy students. Pedagogical theories have the advantage of reducing the likelihood of improving learning through trial and error alone (Morrone & Tarr, 2005), and examples are the cognitive load theory (CLT), social constructivist and metacognitive theories (Terrell, 2006). There is relatively sparse information in international literature on how anatomy for the physiotherapy profession is taught or learnt (Carroll, Tracy-Bee, & McKenzie, 2021; McKenzie & Gutierrez, 2007; Shead et al., 2016, 2018) and the effectiveness is essential to justify the high cost of training physiotherapy students (McMeeken, 2008).

The physiotherapy profession is profoundly dependent on quantitative research methodologies (Johnson & Waterfield, 2004), with less than 4% of its literature employing qualitative approaches during the early 2000s (Gibson & Martin, 2003; Petty et al., 2012). Consequently, our understanding of teaching anatomy for physiotherapy largely arises from quantitative methodologies employing Likert-based questionnaires and is dominated by research based in the United States of America (USA), where four pedagogical patterns emerge. Firstly, physiotherapy schools across the USA and Canada had a tendency for teacher-centered lectures following historical traditions (Abdur-Rahman, 2007; Latman & Lanier, 2001; Mattingly & Barnes, 1994; Reimer et al., 2013), as was the case in Spain (Melguizo et al., 2007). Secondly, anatomical teaching for physiotherapy was typically a precursor knowledge taught in the first year or two of physiotherapy degree programs (Abdur-Rahman, 2007; Berube et al., 1999; Latman & Lanier, 2001; Mattingly & Barnes, 1994; Reimer et al., 2013; Shepard & Jensen, 1990; Thomas et al., 2011), just like in Turkey (Turhan, 2020), Japan (Kawashiro et al., 2009), and South Africa (Shead et al., 2018). Thirdly, there was widespread practice of using cadaveric prosections, as opposed to students carrying out cadaveric dissections (Berube et al., 1999; Reimer et al., 2013), and this was similar to the practice in Japan (Kawashiro et al., 2009). Finally, anatomical teaching in the USA was overwhelmingly focused on the musculoskeletal system (Latman & Lanier, 2001; Mattingly & Barnes, 1994).

Fourteen pedagogical qualitative papers focused on anatomical teaching for physiotherapy were identified, all published in the last 6 years (Carroll, McKenzie, & Tracy-Bee, 2021; Carroll, Tracy-Bee, & McKenzie, 2021; Diaz & Woolley, 2015; Farrell et al., 2015; Fernandes et al., 2015; Killins, 2015; McLean et al., 2015; Moraes et al., 2016; Nicholson et al., 2016; Roberts, 2015; Shead et al., 2019; Smith et al., 2015), except for two earlier ones (Gunn et al., 2012; Ryan, 2011). Most of these papers on anatomy for physiotherapy with qualitative methodologies do not critically engage with the literature of established pedagogical theories, and those that did typically used only a couple of sentences to link their results to a particular pedagogical theory. Of these studies, four did not refer to any pedagogical theory at all (Farrell et al., 2015; Fernandes et al., 2015; Moraes et al., 2016; Nicholson et al., 2016), while the andragogy theory (Taylor & Laros, 2014) or problem-based learning theory (Gunn et al., 2012) were ruled out. None of the 14 papers generated a new pedagogical theory to explain how anatomy was learnt by physiotherapists. Three papers stand out. Helpful qualitative pedagogical concepts to illuminate how anatomy for physiotherapy is taught in South Africa have been explored (Shead et al., 2019). Preliminary work has been made in developing key threshold pedagogical concepts for the USA (Carroll, McKenzie, & Tracy-Bee, 2021) and in advocating for a core syllabus for teaching anatomy for physiotherapy (Carroll, Tracy-Bee, & McKenzie, 2021).

The physiotherapy profession has been slow in developing a qualitative evidence base for anatomical teaching in physiotherapy, and that has curtailed the development of pedagogical theory overarching and tying together most of the teaching activities across the three undergraduate years, and provide better insight into human complexity (Bithell, 2000; Petty et al., 2012). This study proposes a new pedagogical theory based on a qualitative methodology that characterizes and explains the current dominant pedagogical principles used by anatomy teachers in the UK who are physiotherapists. It is anticipated that the application of this theory will promote the long-term learning of anatomy by physiotherapy students during their undergraduate degrees.

2 | MATERIALS AND METHODS

2.1 | Introduction to the research design

The chosen ontology, epistemology, methodology and methods were nominalism, radical constructivism, grounded theory, and interviews, respectively, and were critically examined in a research "onion" sequence (Saunders et al., 2018). Ethical approval (Reference number ERN_17–1013) for the research study was granted by the Research Ethics Committee of the Faculty of Business, Education and Law of Staffordshire University. Grounded theory was chosen because it allows conceptual ideas and their relationships to converge into a theory (Gerrish & Lacey, 2015). Intensive interviews are the mainstay of the grounded theory methodology because they promote dialogue on concepts that arise and allow the interviewers

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to clarify information in real time (Glaser, 1998; Strauss & Corbin, 2014; Charmaz, 2014).

2.2 | Participants

Qualified physiotherapists teaching anatomy modules were chosen as participants because they had the most physiotherapy and anatomy teaching experiences that would have fostered the creation/construction of cognitive rules (based on radical constructivism) of the most effective ways of teaching and learning anatomy and physiotherapy. In addition, physiotherapy trained anatomy teachers are better able to see the clinical relevance of anatomy (Mattingly & Barnes, 1994; McCrorie, 2000) than pure anatomists (Koens et al., 2006; McCrorie, 2000; Scott, 1993). Qualified physiotherapists teaching anatomy are better suited to teach both basic anatomy and the application to clinical domains. Moreover, the opinions of teachers carry more weight than opinions of students (Leung et al., 2006). Integrated physiotherapy modules are much more prevalent in British physiotherapy degree programs than separated modules of basic sciences and clinical subjects (Bithell, 2007) because of curricular influences from the CSP and the Health and Care Professions Council (HCPC) (HCPC-Training-Further-Information, 2022).

The three participant inclusion criteria were physiotherapist registration with the HCPC, lectureship in a British university, and experience teaching anatomy modules to physiotherapy undergraduate students. The eight anatomy teachers interviewed comprised a teaching associate, five lecturers, a senior lecturer and an associate professor who were from a 19th-century university, two Russell Group universities, two Plate-Glass universities, and three post-1992 universities. Males and females were in equal numbers and all were in England, except for one male in Scotland. All, but one, had fellowship with the higher education academy.

2.3 | Procedure

The procedure involved four stages: initial exploratory sampling (using internet-based search and snowballing stages), an evaluation of the quality of potential available participants (Patton, 1990), conducting interviews, and analyzing the interview data. The exploratory sample technique helped determine the size and profiles of the potential pool of anatomy-teachers-for-physiotherapy within the UK, as there was no indication of their number from British literature. A directory of approved physiotherapy training programs available on the HCPC website (HCPC-Register, 2022) was used to locate the 37 approved universities running physiotherapy-training programs in the UK. The contact details of 137 individuals were found, 37 of which were for potential anatomy-teachers-for-physiotherapy, with two being two probable anatomy-teachers-for-physiotherapy and the remainder being staff who may know such teachers. Although some of the contact details from the internet-based search stage were complete, the majority of the information sought was either missing, incomplete, or out of date, and the snowballing stage involved emailing/telephoning proxy contacts to complement and complete the contact details as much as possible. Fifty potential anatomy-teachers-for-physiotherapy were identified from both the internet-based search (37 participants), and the snowballing stages (13 participants) and were sent pre-interview profile surveys to determine their profiles.

Thirteen out of fifty (26%) anatomy-teachers-for-physiotherapy agreed to participate, only nine (18%) completed the consent forms and eight participants (16%) were available for interviews. The eight confirmed participants had a mix of experienced versus new teachers, doctorate versus non-doctorate holders, a range of years spent teaching anatomy, and teaching loads per week. In total, six face-to-face interviews, one Skype interview and one telephone interview were conducted. The eight interviews amounted to a total of 8 h 55 min that generated 72,292 words when transcribed.

Profile surveys and information available on university websites of the participants, their universities and students were used to provide contextual analysis before the analysis with coding techniques. The transcribed texts of the interviews were coded using all the coding techniques (except for Longitudinal and Elaborative coding) previously recommended for a grounded theory methodology (Saldaña, 2013) until data saturation was achieved. The coding analysis took about 300 h. The major themes that emerged were the pedagogical backdrop, pedagogical approaches, and the pedagogical timings that will be described in Section 3.

3 | RESULTS

3.1 | Pedagogical backdrop

There were five pedagogical issues raised in the interviews which formed the pedagogical background: extensive anatomical content, insufficient teaching time, trend towards student-centered tutorial-based teaching, limited ability of students to retain anatomical knowledge, and frequent revisitations of anatomical content by anatomy teachers.

Firstly, there was a common theme expressed that the anatomical knowledge that the undergraduate physiotherapy students must learn is voluminous.

"There is a lot knowledge-based content, so there are a lot of things to remember."

Secondly, all the anatomy teachers stated that they had insufficient time to teach the voluminous anatomical content within their timetables. They, therefore, elected to reduce the volume of anatomical knowledge by focusing on the essential and core anatomical knowledge that was most relevant for physiotherapy practice.

"Time is always pressured, there is a lot to fit in the time that you have."

Thirdly, the way anatomy is taught has changed over recent decades from didactic and lecture-based teaching that was teacher-centered, to student-centered tutorials, where anatomical knowledge is integrated with other relevant disciplines. Fourthly, anatomical knowledge of

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students was described by all participants as transient and diminishing when not being used or reinforced. This knowledge decay caused gaps in the knowledge of students and these gaps were a regular occurrence by all the participants. Fifthly, all the anatomy teachers used teaching activities that reinforced similar anatomical concepts to make knowledge more robust and stronger with each revisitation.

3.2 | The pedagogical approaches

The three pedagogical approaches that were employed by the participants in their teaching practice were visual anatomical imagery, kinesthetic anatomical skills, and the clinical application of anatomical knowledge. Examples of teaching aids supporting each approach are outlined in Table 1.

Visual anatomical imagery was defined as using highly visual anatomical learning aids to stimulate more efficient learning outcomes of anatomical knowledge among physiotherapy students, and it was a strong and consistent theme in all interviews. Visual anatomical imagery was considered to make learning anatomy quicker and more efficient due to the inherently visual nature of anatomical sciences. The kinesthetic anatomical skills were defined as an "experimental learning of anatomy" that uses factual anatomical knowledge, visual anatomical imagery, being able to palpate anatomical structures beneath the skin, understanding how anatomical structures feel and look like when they are moved, and analytical and problem solving skills.

There was a firm thread across all the teachers of applying anatomical knowledge to a wide spectrum of clinical physiotherapy situations, and that type of teaching was delivered in two teaching phases: teaching environments with no real patients during the first year, followed by teaching environments with real patients during the second and third years. In creating teaching environments without real patients, clinical mini scenarios were used and were characterized by the use of anatomical knowledge to help understand, solve problems, assess and treat fictitious or historical clinical presentations and problems, usually within a teaching session. Clinical mini scenarios were used on 1st year physiotherapy students because they had limited clinical physiotherapy knowledge. The general strategy of teaching anatomy on real patients occurred largely in student placements and clinical teaching sessions during the second and third years. Learning clinical anatomy was achieved by making students anatomically inquisitive and asking themselves how anatomy is involved in the various patient conditions they were coming across. The anatomical inquisitiveness was intended to expose their gaps in anatomical knowledge and trigger the students to restore and revitalize the gaps in their knowledge.

3.3 | Pedagogical timings of the pedagogical approaches

The Pedagogical Timings refers to when the three pedagogical approaches of visual anatomical imagery, kinesthetic anatomical skills,

TABLE 1 An overview of how the pedagogical approaches were related to pedagogical timings.

Year	Teaching activity	The three pedagogical approaches		
		Visual anatomical imagery	Kinesthetic anatomical skills	Clinical application of anatomical knowledge
1st Year	Independent Study	• Online imagery (Lecture PowerPoints with voice overs, digital illustrations, videos) • Books (diagrams, photographs, illustrations) • Anatomical software	• Personal set of plastic skeletons loaned to each student for the year	• Clinical mini scenarios in anatomy textbooks
	Practical Anatomical Tutorials	• Live sketching by the teacher • Cadaveric specimens • Plastic anatomical models or skeletal parts • Anatomical learning aids • Analyzing movement through observation • Images from ultrasonography • Video recordings of students in an anatomy practical	• Manipulating plastic anatomical models or skeletal parts • Interacting with anatomical learning aids • Manipulating cadaveric specimens • Palpating other students	• Anatomy-for-physiotherapy-teachers discussing and solving clinical mini scenarios • Physically assessing simulated patients
2nd Year and 3rd Year	Student Clinical Placements	• Imagining anatomical structures beneath the skin • Interpreting radiological images	• Physically assessing patients • Being able to select and perform the appropriate diagnostic palpatory tests to confirm impaired anatomical structures	• "Embedding" anatomy into every clinical physiotherapy work • Grooming anatomical inquisitiveness during clinical physiotherapy work • Students developing anatomical hypotheses of clinical problems

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and clinical application of anatomical knowledge were used in the teaching activities of a typical undergraduate physiotherapy degree program. The Pedagogical Timings do not indicate the absolute presence or absence of pedagogical approaches, but rather times of the most intensity. The pedagogical timings were divided into two major phases: first-year phase (Independent student learning and Tutorial based learning) and the joint second- and third-year clinical phase.

The first-year independent student studying phase was typically considered by all the anatomy teachers to be the optimal time for learning the more factually based anatomical knowledge as a preparatory phase for the subsequent practical anatomical tutorial phase. Practical anatomical tutorial learning was deemed to be the most significant teaching activity in terms of financial cost, effort spent, and time spent by teachers during the first year of the physiotherapy undergraduate degree program. The tutorial-based learning was anchored in practical teaching, as exemplified by:

"So, for the practical sessions, we will look at applied, basic observation skills, we are looking at observation, palpation and movement analysis as well."

During tutorials, the most basic and essential anatomical knowledge was taught due to limited teaching time; "We only focus on the basics".

Core anatomical knowledge was divided into two categories: principles on broader organizational design of anatomical structures, and principles on the functionalities/roles of anatomical structures. There were two types of anatomy practical tutorials: practical classroom anatomy tutorials and laboratory cadaveric tutorials. The practical classroom anatomy tutorials were typically characterized by students palpating each other or palpating hired human models on adjustable beds, and were rich in various anatomy learning aids. Six of the eight schools had laboratory cadaveric tutorials that are heavily regulated by the Human Tissue Authority and the Human Tissue Act of 2004.

Several features influenced anatomical teaching during second- and third-year clinical placement-based learning. Seven anatomy teachers taught most of the anatomical knowledge during the 1st year, while the clinical lecturers and the practice placement educators applied the anatomical knowledge to physiotherapy clinical situations during second and third years. There was a realization shared by all teachers that physiotherapy students cannot be expected to know all the anatomical knowledge necessary to underpin every clinical field of physiotherapy.

"We know we can't teach (everything), we know that we can't assume students will have the knowledge of every (anatomical) system in the body."

As a pragmatic solution, students were expected to have the anatomical knowledge related to the clinical area of physiotherapy they were currently placed in.

There were implicit and explicit ways of teaching anatomy during the clinical placements. The implicit teaching of anatomy during the clinical placements was hallmarked by seven anatomy teachers assuming that the clinical student placement supervisors knew what anatomical knowledge and skills to teach, and how to teach and evaluate the anatomical teaching of physiotherapy students during the clinical placements. There was no established and regular communication between the anatomy teachers for physiotherapy and the clinical student placement supervisors.

The explicit teaching of anatomy during the clinical placements was characterized by an anatomy theme lead at one university who led anatomical teaching on both the BSc Physiotherapy degree and postgraduate anatomy degrees specially designed for physiotherapists, and was the anatomy laboratory dissection link tutor for physiotherapy. The anatomy theme lead intentionally promoted the sharing of curricular information, feedback, and ideas for teaching anatomy during the clinical placements among the students, anatomy teachers, and the clinical student placement supervisors. The anatomy theme lead also strategically managed anatomical teaching for first-year undergraduate physiotherapy students right up to postgraduate physiotherapy students. In contrast, the anatomy teachers in physiotherapy schools with implicit clinical teaching of anatomy had no explicit teaching influence on the clinical student placement supervisors and students on placements during the student clinical placements. The influence of the anatomy teachers with implicit teaching was largely restricted to the one or two modules with significant anatomical tutorials that the teachers taught on.

4 | DISCUSSION

The descriptions of the pedagogical backdrop, pedagogical approaches, and pedagogical timings from the results section have been reorganized and grouped in the discussion as the five major pedagogical principles of the cognitive-load theoretical frameworks and its sub-variant four-component instructional design model (4CID model) to make it easier to critically examine their descriptions, theoretical underpinning and future implications. The 4CID model promotes the gradual learning of knowledge and skills by students of complex and authentic real-work place tasks in increasing fidelity, and has been shown to be effective among medical students (Vandewaetere et al., 2015) and physiotherapy students on clinical placements (Boekhout et al., 2011).

The working definition of a pedagogical principle is a fundamental and generalizable assumption that influences teaching conduct and actions, and is anchored on findings of good practice (Atjonen et al., 2011). The five major discussion pedagogical principles are spiral curriculum strategies, the use of visual anatomical imagery, the use of kinesthetic anatomical skills, strategies for teaching the clinical application of anatomy, and using anatomical principles for metacognition.

An introduction to the CLT will help better understand the Discussion section. The CLT is the most prominent theory on instructional design (Gerjets et al., 2009) in educational psychology (Plass et al., 2010) and it suits anatomy (Terrell, 2006). Learning activities have to be carefully designed to avoid overloading the working memory (Sweller, 1988; Sweller et al., 1998, 2011), which has a limited processing capacity of four to seven elements at any one time (Cowan, 2010; Paas & Sweller, 2014). The processed information is then archived permanently into the long-term memory, which has an

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infinite (Young et al., 2014) or near infinite (Paas et al., 2003; Simon & Gilmartin, 1973) capacity.

The CLT has three types of cognitive loads: extraneous, intrinsic, and germane loads. The extraneous cognitive load is caused by preoccupying the working memory with irrelevant elements and consequently should be minimized (Chandler & Sweller, 1991; Moreno & Park, 2010). The intrinsic cognitive load is governed by the inherent difficulty of the material to be learnt (Moreno & Park, 2010; Plass et al., 2010; Sweller, 1993), and needs to be effectively managed, as some problems or educational tasks are intrinsically more difficult to resolve than others (Moreno & Park, 2010). The germane cognitive load, which has to be maximized, aims to make future cognition easier and more efficient (Moreno & Park, 2010; Schnotz & Kürschner, 2007; Sweller, 1988) by intentionally applying learning tactics, seeking patterns, reorganizing problems to best solve them, supervising metacognition and learning, and reflecting on learning (Schnotz & Kürschner, 2007).

4.1 | Spiral curriculum strategies

The spiral curriculum version of CLT and 4CID was the chosen curricular models that could the best explain the timings of the results using the triad of the sequencing principle of learning content sequenced in increasing complexity (Mayer & Moreno, 2003; Sweller, 1999), the fading principle of diminishing teaching support with time (Wijnen-Meijer et al., 2009) and the reinforcement principle of revisiting similar content over time (Merriënboer & Kester, 2014), respectively. The triad echoes the traditional spiral curriculum with four main characteristics: the revisiting of topics, visitations at progressively higher levels of cognitive difficulty, the later visitations referring to earlier learning encounters [rather than "one shot affairs" of learning (Kabara, 1972)], with the competency of students increasing with each visitation (Harden, 1999).

The teaching and learning of voluminous and challenging anatomy was arranged in a certain sequence to make the learning more manageable. Earlier anatomical information was more separate and isolated, while later ones were more integrated and complex, as indicated in Table 2. The gradual building up of teaching content in spiral learning reduces the likelihood of overwhelming the students with knowledge (Harden, 1999). The CLT and the 4CID theoretical models use the sequential principle progressively to develop certain knowledge, skills and attitude threads (Merriënboer & Kester, 2014). The sequencing principle initially promotes the learning of components of a complex task separately and integrates them toward the end, lowering the intrinsic cognitive load (Merriënboer & Kester, 2014). A more spread-out learning of anatomy is preferable to congested learning in a shorter time period (Terrell, 2006).

The fading principle was characterized by the teacher support of the physiotherapy students being typically front-loaded and then tailing off in a disorganized manner towards the end. Specifically, student support provided by anatomy teachers for physiotherapy was explicit and extensive during the 1st year but was greatly reduced and implicit during the second and third years. The reduction in support was characterized by poor, informal and ineffective communication, collaboration, and discussions between anatomy teachers for physiotherapy and the clinical lecturers or student supervisors. The exception was one teacher who intentionally reduced their teaching support gradually and had an explicit program of anatomy learning during clinical placements in the second and third years.

The fading principle of the CLT (Merriënboer & Sweller, 2010; Renkl et al., 2004) and 4CID theory (Merriënboer & De Croock, 1990, 1992), alternatively called the scaffolding principle (Merriënboer & Kirschner, 2013), describes how support from the teacher gradually reduces, as the sophistication and automation of the schemas in the long-term memory of students increases. Insufficient teaching support can be detrimental to learning, and acceptable support has to be of the right type, amount and timing (Merriënboer et al., 2003). Teaching support should ideally ensure that the learning demands placed on the students should be gradual, have "a smooth transition," and not have "abrupt changes" (Renkl et al., 2004, p. 62) or cliff-edges (Renkl et al., 2002).

The "reinforcement and repetition principle" saw the revisitation and reinforcement of similar anatomical knowledge and skills in the later teaching sessions, with progressively increasing phases of complexity and competency, whilst also integrating new knowledge of other subjects. The role that repetition and reinforcement played within a spiral curriculum was to restore partially forgotten knowledge and skills by physiotherapy students, a long known view (Kabara, 1972), because most of us forget information on a daily basis (Loftus & Loftus, 1980). Anatomical knowledge attrition has been confirmed in physiotherapy students (Anderson & Conley, 2000; Manisha et al., 2017; Turhan, 2020). After initial learning, a process of forgetting and then reconstructing knowledge is essential before applying anatomical knowledge to clinical situations (Smith & Mathias, 2011). There was also a long-term memory limit of anatomical knowledge that the physiotherapy students could remember. However, the

TABLE 2 The typical sequence of anatomical teaching across the 3 years.

	Anatomical content
1st Year	Teaching and learning *isolated* basic anatomy. Started with isolated bones, then isolated muscles, then how muscles functioned.
	Teaching and learning *unified* basic anatomy. Physically assessing healthy patients (fellow students).
2nd Year	Revisiting 1st year basic anatomy.
	Teaching the clinical application of anatomy in musculoskeletal, cardiorespiratory and neurological physiotherapy.
	Applying anatomical knowledge on patients with clinical cases *under supervision* in hospitals.
3rd Year	Applying anatomical knowledge to patients with clinical cases with *less supervision*.
	Students undertaking a module called "Physiotherapy management of patients with demanding and complex conditions".

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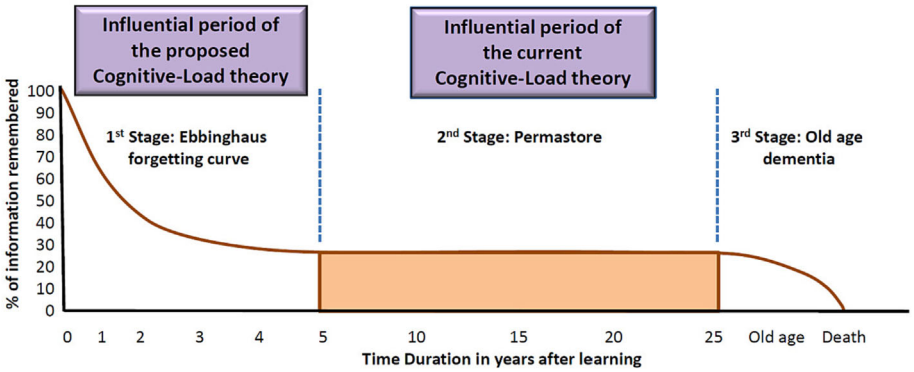

FIGURE 1 The amended CLT in the forgetting timeline. Please note that the time duration is not in a linear time scale.

forgetting of information in a long-term memory with limited storage capacity contradicts the pillars of the CLT that sees information in the long-term memory as a permanent (or near-permanent) store of information with an unlimited (or vast) capacity (Paas et al., 2003; Paas & Sweller, 2014; Simon & Gilmartin, 1973; Young et al., 2014). The CLT may have made two overreaches in supporting the permanence of memories in the long-term memory. It was based on memories surviving over ten years (Paas et al., 2003; Paas & Sweller, 2014; Simon & Gilmartin, 1973; Young et al., 2014), while in contrast, the learning and assessments in schools and universities are on shorter annual cycles. In addition, the CLT is based on memories of experts (Amidzic et al., 2001; Chase & Simon, 1973; Simon & Gilmartin, 1973), while most of the teaching in schools and undergraduate degree programs is to novice learners. The stable schema in the long-term memory of the CLT (Amidzic et al., 2001; Chase & Simon, 1973; Simon & Gilmartin, 1973) appears comparable to the tenaciously stable permastore, which has "immunity against forgetting" (Bahrick, 1984; Neisser, 1984) and eventually declines in old age (Bahrick, 1984). On the other hand, novice anatomy learners in this study had more fragile and temporary schema, which matches the much earlier "Ebbinghaus: curve of forgetting" period with an exponential decay, as shown in Figure 1.

4.2 | Visual anatomical imagery

There was a strong visual theme that emerged from the interviews. The significant visual element in teaching anatomy can be explained in that gross anatomy, the major branch of anatomy that was taught to physiotherapy students, is defined by sight (Turhan, 2020), where "gross" means something large or "of conspicuous magnitude" (Online-Oxford-English-Dictionary, 2016), like structures seen on prosections with the naked eye. Anatomical teaching is similar because it is taught through talking, rich pictorial imagery in recommended anatomy textbooks, visual-based and haptic-based anatomical dissections, and palpations of anatomical structures on patients (Biasutto et al., 2006; Collett et al., 2009; Finn et al., 2011; Tam et al., 2010). The extensive imagery in teaching and learning anatomy justifies considering the Dual-Coding theory and its educational implications. The CLT incorporated Paivio's dual-coding theory that views visual information being processed by the nonverbal cognition architecture (Clark & Paivio, 1991; Paivio, 1991). It is well known that some teachers and students use the imagery system more strongly than others, causing them to have an imagery advantage in learning (Clark & Paivio, 1991). This advantage may make "imagery gifted" physiotherapy students learn more from pictorial/graphic learning opportunities than the less imagery gifted students. Many of the anatomy teachers in the current study identified themselves as "visual learners," and this mirrors others who have self-reported that they learnt better if there is a visual aspect (Mayer & Massa, 2003).

4.3 | Kinesthetic anatomical skills

There was a strong tactile and haptic anatomical multimedia theme across all the anatomy teachers. Most of the schools of physiotherapy used prosections, rather than dissecting cadavers, because they were more time efficient (Abu-Hijleh, 2010; Bandaranayake, 2010), and was similar to the practice used in schools of physiotherapy in the USA (Latman & Lanier, 2001; Reimer et al., 2013) and Japan (Kawashiro et al., 2009). This study used practical anatomy tutorials, conducted in classrooms and not laboratories, as the main teaching activity for providing haptic-based anatomy learning and differed from the practice in the USA (Abdur-Rahman, 2007; Berube et al., 1999; Latman & Lanier, 2001; Mattingly & Barnes, 1994; Melguizo et al., 2007; Prados et al., 2007; Reimer et al., 2013; Thomas et al., 2011), where cadaveric-based teaching was their main teaching activity for haptic based anatomy learning. The use of anatomy practical tutorials in the UK may be due to regulatory pressure from the CSP for physiotherapy schools to run practical skills sessions/tutorials (CSP, 2022).

There is a tendency among CLT scholars of undervaluing the non-visual sub-components (environmental sounds, human actions, haptic, and visceral sensations) of the nonverbal mental system by only describing the visual sub-system (Paivio, 1991). The downplaying of haptic input becomes apparent when most learning of basic sciences has been noted to be about facts and not skills (Scott, 2000). The 4CID model makes a break from all the other learning theories based on the CTL by emphasizing skills, and not just knowledge (Merriënboer, 1997; Merriënboer et al., 1992, 2002; Merriënboer & Kirschner, 2013).

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4.4 | Strategies for teaching the clinical application of anatomy

Anatomical knowledge related to the musculoskeletal system was the most frequently mentioned body system by the anatomy teachers in the study and is in line with the literature (Latman & Lanier, 2001; Mattingly & Barnes, 1994). The anatomy teachers used the fidelity principle, the variability principle and the completion principle of the 4CID model to teach the clinical physiotherapy relevance of anatomical knowledge.

There is a persuading philosophy that anatomical learning should support physiotherapists working in clinical settings (Latman & Lanier, 2001), which is supported by the fidelity principle of the CLT and 4CID, whereby the students learn in environments mimicking their future career settings (Merriënboer & Kirschner, 2013). The fidelity principle describes a learning progression where students start by learning from textual descriptions of clinical cases, then from fellow students simulating patients in poor health, and eventually from real life patients (Merriënboer & Kirschner, 2013). Initial extremely high fidelity teaching hinders learning in novice learners (Harp & Mayer, 1998; Mayer et al., 2001) and underscores the need to gradually increase the complexity of fidelity (Merriënboer & Kirschner, 2013), as was done in the current study.

The physiotherapy students were encouraged to palpate as many different bodies as possible during the practical anatomy tutorials. Physiotherapy students went to many different clinical rotations during the second and third years and these rotations ranged from musculoskeletal, cardiorespiratory to neurological clinical placements, where they saw as many different conditions as possible. According to the variability principle of the 4CID and CLT, robust learning is believed to be promoted when a student is exposed to a wide variation of life situations (Merriënboer & Kirschner, 2013) and that then promotes learning transfer (Cormier & Hagman, 1987). Learning through variable practice is thought to occur through a process of inductive learning, where students construct more general cognitive schema to account for the concrete variable practice (Merriënboer & Kirschner, 2013), especially where there is high contextual interference (De Croock et al., 1998; De Croock & Merriënboer, 2007; Helsdingen et al., 2011a, 2011b).

According to the completion principle, learners learn better if they are initially given worked examples, then partially worked out examples, and eventually full problems to solve, as opposed to perpetually giving the students worked examples or conventional unworked problems (Renkl, 2014). The completion principle also requires the curriculum to be spirally designed and set out in increasing levels of complexity as the automation of tasks becomes more subconscious and efficient (Sweller et al., 1998).

4.5 | Anatomical principles

The fifth major pedagogical principle was that anatomy teachers taught their physiotherapy students to focus on anatomical principles, as a way of coping with the voluminous "index knowledge" of anatomy within narrow time constraints. Anatomical principles in this study created metacognitive schemata that helped the students to benchmark anatomical knowledge. Metacognition enables students to best strategize the solving of a cognition problem, oversee the understanding of a learning task, and how well the task is successfully completed (Schnotz & Kürschner, 2007). The anatomy teachers taught benchmarking schema of the generic organization of anatomical structures in the human body that applied to multiple areas in the body. The other type of benchmarking schemata predicted the functional abilities (or lack of) of anatomical structures on patients.

Principles of knowledge, as opposed to names, are easier to remember (Conway et al., 1991; Scott, 2000) and are more likely to integrate into existing schema (Bahrick, 1992) and to be housed in the permastore (Conway et al., 1991). Generalisable schema on trees (Sweller, 1994), for solving geometry problems (Koedinger & Anderson, 1990) and for word-based problems (Low & Over, 1990) has a wider appeal and can be applied across a wider spectrum of problems than specialized schema. Principles of basic sciences last longer in the long-term memory than facts (Scott, 2000). Anatomical principles have a more universal application, are more potent and make them more likely to be frequently used than an "index anatomical knowledge" (Louw et al., 2009).

The results of primary cognition could be compared with the benchmarking schemata for generic anatomical organization or for predicting functional outcomes, with the differences used to self-regulate their primary cognitions. If there was a difference, then metacognition could redirect the cognition system to re-start the analysis of the primary cognition again to see if there was a processing error or try and account for the difference. The more general schema could also be recruited when a student lacks specific schema to answer specific questions (Neisser, 1984; Renkl et al., 2004) to reconstruct the forgotten schema required to solve anatomical problems or predict answers. These general anatomical principles are now regarded as "necessary intellectual tools" for students (Louw et al., 2009, p. 377).

At a theoretical level, the use of anatomical principles for benchmarking matches the germane load of the CLT. The germane load is a metacognitive load, where students review their primary thinking or cognition (Schnotz & Kürschner, 2007) to enhance future learning (Sweller et al., 1998). Teachers were encouraged to increase the germane cognitive load as much as possible to below the maximal capacity of the working memory (Ayres & Sweller, 2005) by using explicit metacognition strategies (Cutting & Saks, 2012).

4.6 | The relationships between the five dominant pedagogical concepts

The relationships between the five major pedagogical principles and the CLT are illustrated in Figure 2.

Figure 2 shows the five dominant pedagogical concepts from the current study in green boxes and their relationships to the CLT and 4CID theoretical models (Sweller et al., 1998; Terrell, 2006;

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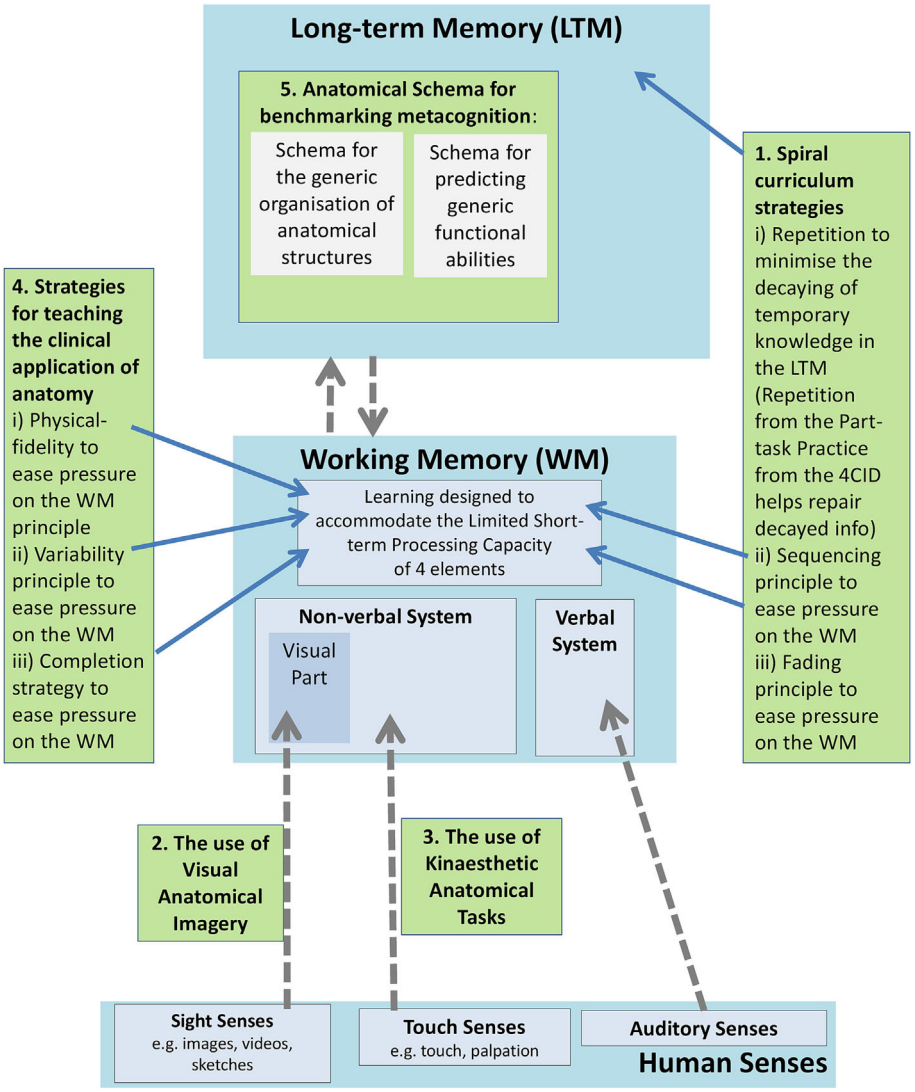

FIGURE 2 The relationships between the five dominant pedagogical concepts to the CLT and 4CID theoretical models.

Merriënboer & Kester, 2014) in light blue boxes. Figure 2 illustrates the brain cognitive machinery in blue boxes and how it handles the five dominant pedagogical concepts of the discussion section in green boxes. The blue "Human sense" box lower down generates sensory information from the sight, touch, and auditory sensory organs which send the information using broken gray arrows to the verbal and non-verbal components of the working memory. The working memory processes the information and then sends the information using broken gray arrows to the long-term memory to be stored as anatomical schema. The five dominant pedagogical principles are shown in Green boxes and are numbered from 1 to 5 according to the sequence of how they were introduced in Section 4. All the five dominant pedagogical principles are geared toward making the working memory work more efficiently, except for Point 1(i) and Point 5, which are aimed at making the long-term memory work more efficiently.

Figure 3 shows the four new proposed CLT theory deviations in yellow boxes (lettered from A to D) and their relationships to the five dominant pedagogical concepts from the current study in green boxes and to the CLT and 4CID theoretical models (Sweller et al., 1998; Terrell, 2006; Merriënboer & Kester, 2014) in light blue boxes. These four deviations constitute how the new proposed CLT differs from the existing CLT and 4CID frameworks.

4.7 | Recommendations

Several recommendations are being proposed. It could be argued that current typical anatomical teaching suffers from being too modularized, while the principle of the spiral curriculum extends beyond the responsibilities of single disciplines/departments (Kabara, 1972) or modules taught at campuses/hospitals. An anatomy theme lead could be appointed to manage the following across the physiotherapy degree: the over-arching spiral curriculum in terms of the sequencing of teaching content, the fading principle of gradually decreasing levels of teaching support for students, and promoting reinforcement of anatomical knowledge in later sessions. The anatomy theme lead could also help avoid the detrimental lack of staff continuity of teaching anatomy spread across several modules, also noted in South Africa

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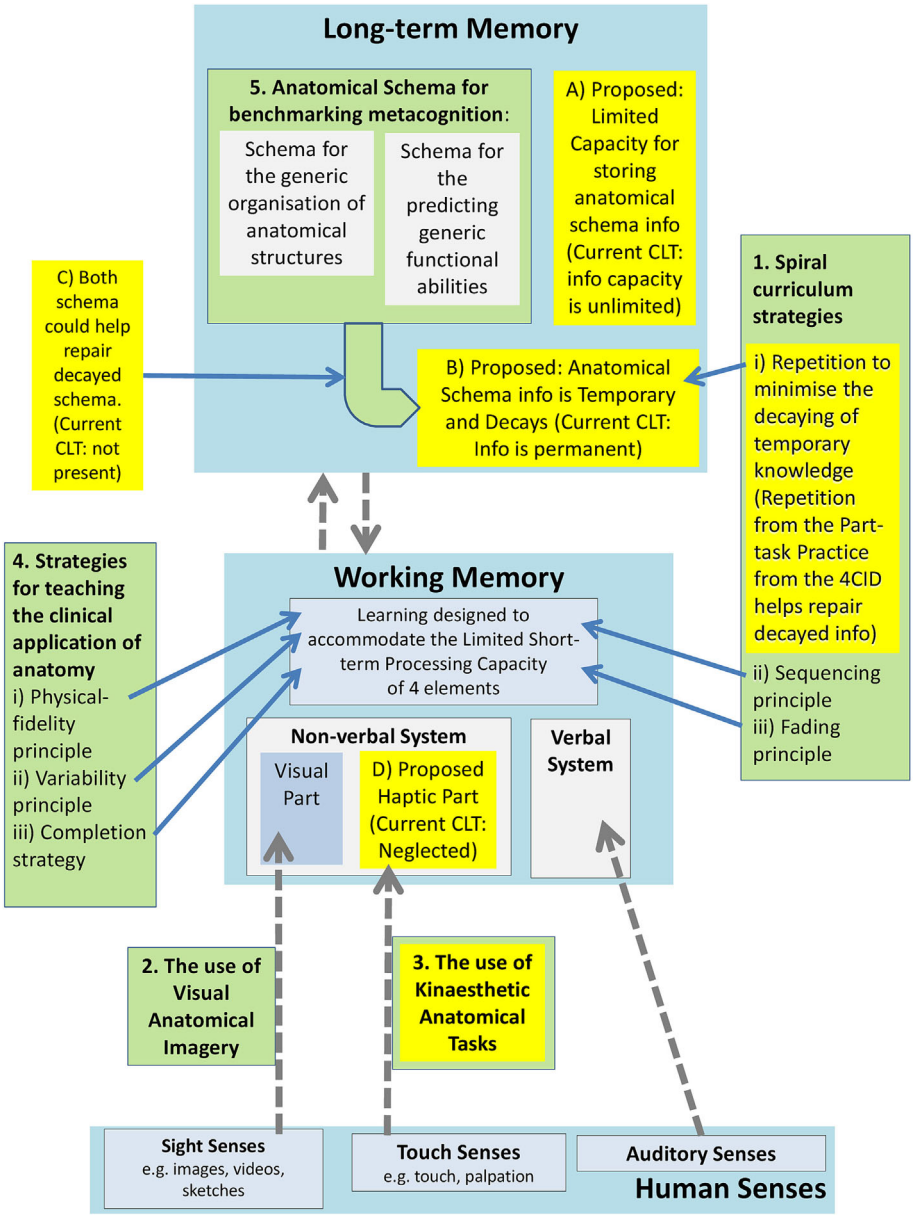

FIGURE 3 Four new proposed CLT theory deviations.

(Shead et al., 2019). The current teaching in typical anatomy modules during the 1st year is overloaded, and the anatomy theme lead could resolve this congestion by introducing explicit anatomy teaching into the later clinical years. The extraneous cognitive load of students could be reduced (Kalyuga et al., 1999) by creating the much anticipated core anatomy curriculum for physiotherapy students (Carroll, Tracy-Bee, & McKenzie, 2021; Gangata & Vigurs, 2017; Shead et al., 2018), which includes a set of general anatomical principles, and suitable online educational materials (Turhan & Yakut, 2020).

There was a lack of specialist anatomical training and experiences in all but one of the anatomy teachers in the current study, when they took up their first anatomy teaching job, and support would be welcomed for entry-level teachers. A new version of the CLT is being proposed with three pillars: the learners are novice learners, the long-term memory of novice learners stores temporary knowledge, and thirdly, their long-term memory has a limited capacity. In contrast, the traditional CLT features experts possessing a long-term memory with permanent and infinite capacity (Young et al., 2014). In addition, novice anatomy learners had greater kinesthetic input and stronger metacognition to help repair forgotten anatomical knowledge. The new proposed CLT may have a broader appeal across the wider anatomical education. Action research would be welcome to test and evaluate the pedagogical concepts associated with the main findings of the current research in different learning environments and disciplines.

There were some limitations. There are many universities within the UK and abroad that are taught by anatomy teachers without physiotherapy clinical training and experiences, whereas only physiotherapy-based anatomical teachers were used in the present study. Non-physiotherapy anatomy teachers were excluded in the study because anatomy teachers who were physiotherapists better understood from their past clinical physiotherapy experiences how students would use anatomy in daily clinical physiotherapy work, and

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how basic anatomical knowledge could be gradually developed to underpin effective clinical physiotherapy practice. Only seven educators were interviewed, and the data generated required about 300 hours to analyze (data saturation was achieved). Future work might examine the development of clinical anatomical knowledge of students largely taught by non-physiotherapy anatomy teachers. There were clinical physiotherapy teachers who taught anatomy during the second and third years who played a peripheral teaching role when compared to the first-year anatomy-teachers-for-physiotherapy. The richest overview description of teaching anatomy and most dominant teaching strategies can be best obtained from those who made the largest contribution to teaching anatomy and who are most likely to think of anatomical pedagogy. Future studies could explore the dominant pedagogical principles from the perspectives of the physiotherapy students. The results of the current study were more heavily weighted toward the first year of the physiotherapy degree programs because this is where the 1st year anatomy-teachers-for-physiotherapy had first-hand experiences, while the anatomy teaching for the remaining undergraduate years were based on second-hand experiences.

5 | CONCLUSION

In conclusion, the pedagogical development of anatomy teaching for physiotherapy has received inadequate attention worldwide (Shead et al., 2016; Turhan, 2020) and in the UK (Gangata & Vigurs, 2017). The current study has made progress by characterizing the five dominant pedagogical principles used by anatomy-teachers-for-physiotherapy. These principles have credibility within the medical education literature (Cutting & Saks, 2012; Paalman, 2000). A new version of CLT has been proposed that accounts for forgetting, a long-term memory with a limited capacity, using haptic learning in practical-based fields, and metacognition to repair forgotten information.

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ORCID

Hope Gangata https://orcid.org/0000-0002-2085-6848

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