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Investigating the Benefits of Integrated Anatomy Instruction: A Cognitive Load Theory Perspective

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ABSTRACT

Declining anatomy knowledge of junior doctors has been linked to clinical error judgement and medicolegal litigation. To overcome the problem, anatomy educators have introduced many teaching initiatives during undergraduate study that might promote anatomy knowledge acquisition and retention, including anatomy teaching using integrated instruction. Anatomy instruction can be integrated in terms of its contents and teaching approach. Learning from integrated anatomy instruction allows students to relate anatomy subjects with different subdisciplines and to comprehend related clinical context for future application. On the other hand, the integrated approach for anatomy teaching caters to different types of learning styles, therefore ensuring optimal learning. Nevertheless, causal relationships between integrated anatomy instruction and student learning has never been explicitly explored. Hence, this article aims to unearth the elements of integrated anatomy teaching that promote learning through instructional design theory, namely, cognitive load theory (CLT).

Keywords: *Horizontal integration, Vertical integration, Cognitive load theory, Integrated teaching, Anatomy knowledge*

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INTRODUCTION

Anatomy is an important basic science subject in medical education due to its high clinical relevance (1–2). Having adequate anatomy knowledge is a prerequisite for safe clinical practice, as such knowledge is essential for performing physical examinations, clinical procedures and surgical interventions (3–4). There is an increasing concern among clinicians about the high incidence of surgical error and medicolegal lawsuits, which could be due to the insufficient anatomy knowledge of medical practitioners (5–9). Physicians and surgeons universally affirm that the anatomy knowledge of medical graduates is critically poor and lower than the acceptable levels for safe clinical practice (4, 10). Likewise, several medical students are insecure about their anatomy knowledge and their ability to apply this knowledge efficiently (11). Such perceived suboptimal anatomy knowledge has triggered anatomy educators to reimagine the anatomy curricula, particularly in relation to its contents and teaching approaches (12).

Despite the emergence of technology-enhanced teaching in medical education, anatomists have not been able to come to consensus on the best teaching method for anatomy (13–14). There is an ongoing debate on how much to teach, when to teach and how to teach gross anatomy to medical students (15). In fact, there are several teaching approaches in anatomy, and they normally depend on the curriculum and teachers' preferences. Some anatomy lecturers prefer to teach anatomy through cadaveric dissection because they believe this teaching approach is highly ranked by students as an effective method for three-dimensional (3D) visualisation (16). However, because of the limitations in conducting cadaveric dissection, anatomy lecturers have resorted to using plastinated specimens, anatomy models and technology-enhanced tools to facilitate student learning (17–19). Others prefer teaching anatomy through lectures, supplemented by student-centred learning activities such as team-based learning (TBL) and problem-based learning (PBL) (20–24). Despite these developments, there is a scarcity of evidence generated from well-designed studies to indicate the best teaching method for anatomy (15).

Notwithstanding the continuous effort to find an effective teaching method for anatomy, educators need to consider another important aspect of anatomy that might affect students' learning: medical students often perceive anatomy as a dry and content-driven subject that is cognitively challenging (25). The intrinsically complex nature of this subject can suppress their motivation to learn, thus resulting in cognitive overload. Introducing a new teaching method does not necessarily contribute to learning as it can also impose a cognitive burden on students, especially when teaching materials are poorly designed (26). Hence, it is important to add value to the instruction content so that students could appreciate the gist of learning anatomy and overcome the content-driven nature of the subject. One way of achieving this goal is by introducing integrated anatomy instruction.

Integrated anatomy instruction refers to teaching that incorporates the topic of anatomy with related topics from other subjects that are typically taught separately. This form of instruction can either be horizontally integrated (i.e., integrating an anatomy topic with related topics within anatomy subdisciplines or with topics from other basic science subjects) or vertically integrated (i.e., integrating an anatomy topic with subjects learned during clinical years) (27). In addition, integrated anatomy instruction can be viewed as combining various teaching approaches, an example of which is the blended learning approach (28). This integration would add additional values to the importance and relevance of learning anatomy, as well as providing an engaging ambience for learning (29). Nevertheless, designing integrated content and teaching approach should be based on a strong theoretical framework to ensure achievement of learning outcomes.

THE COGNITIVE LOAD THEORY AND HUMAN COGNITION

Cognitive load theory (CLT) is an instructional design theory that describes the use of empirically proven teaching strategies for effective learning (30). Despite the argument that CLT is not a cognitive theory strongly related to neuroscience, the principles of CLT were based on the strong foundation of human cognitive architecture and they have been proven to be effective in managing the cognitive load (31–33). It has also been demonstrated that CLT principles are connected with emotion, which affects motivation and eventually influences cognitive processing (34).

Human cognition comprises three types of memory: namely, sensory, working and long-term memory (33). The sensory memory receives unlimited input from the external environment (e.g., visual, auditory, tactile and olfactory input), which are detected by sensory receptors that store them for ultra-short duration. If a learner pays attention to an input, this input will be transferred to the working memory for further processing. Inputs that are out of the learner's focus will decay and will not be processed (35).

The input received by the working memory will be then converted into schema (an organised storable form of information), which will be further encoded to the long-term memory (33). Nevertheless, the working memory has a very limited processing and storage capacity as it can only process three to five chunks of information at a time (36). The storage duration of working memory is approximately 20 seconds; hence, the schema needs to be transferred to the long-term memory within the stipulated duration to ensure learning. Actual learning is said to occur if the long-term memory, which has unlimited storage capacity, has successfully received and stored the schema. When the schema is successfully constructed by the working memory, a learner will understand the content learned. However, the actual learning occurs only when this schema is successfully stored in the long-term memory (37).

The stored schema in the long-term memory is now known as knowledge. With the presence of retrieval cues, this knowledge can be retrieved back to the working memory to be integrated with new information received from the sensory memory and is thus known as prior knowledge (38). The integration process in the working memory expedites the construction of new schema as the learner does not have to spend his or her working memory resources to process the prior knowledge. Hence, more schema can be constructed within the limited capacity of working memory, and more knowledge is stored in the long-term memory.

It should be highlighted that the foundation of CLT is built on five principles of the human cognitive function. The first is the information store principle, which provides a justification for the occurrence of actual learning. Actual learning occurs when there is a change in the long-term memory store. Therefore, an effective instruction should allow transfer of information from the working to the long-term memory, which eventually results in the accumulation of a large amount of knowledge in the long-term memory (39).

Second, the borrowing-and-reorganising principle suggests that knowledge could be efficiently "borrowed" from others, rather than through random self-discovery, which is cognitively demanding. The "borrowed information" is then reorganised in one's working memory through schema construction and stored in the long-term memory. Hence, CLT suggests that novel instruction should be communicated from a knowledgeable instructor to novice learners, rather than through unguided random self-discovery by the novices themselves (40).

Likewise, the third principle—randomness-as-genesis principle—describes the self-discovery of novel information as cognitively demanding, as it appears like a trial and error process that utilises a large amount of cognitive resources (41). Hence, CLT suggests that an effective instruction should be able to instil relevant information into the learners' long-term memory prior to learning new information. Therefore, the learning process would be less cognitively demanding (41).

The fourth principle, which is the narrow-limit-of-change principle, states that the long-term memory alteration must occur in a slow and incremental manner so as not to jeopardise the previously constructed knowledge (42). To ensure such change, the amount of new and novel information that enter the working memory must be controlled to avoid a sudden massive alteration to the long-term memory. Hence, CLT posits that instruction should be designed in a manner that would not exceed the limited capacity of the working memory (43).

The last principle, which is the environment-organising-and-linking principle, states that massive amounts of organised information could be transferred and processed from the long-term memory to the working memory. In other words, the working memory has unlimited capacity while processing familiar information. Based on this principle, CLT outlines the differences between expert and novice cognitive ability; therefore, instructions should be designed based on the learners' expertise level (44).

THE COGNITIVE LOADS

Designing an integrated instruction requires understanding of the different loads that can burden the human working memory. The CLT outlines three types of cognitive loads: namely, intrinsic, extraneous and germane loads (26). The intrinsic load is imposed by the complex nature of an instruction, which is determined by two factors: the number of information units that are present in the instruction and the relationships among them (26). A complex subject such as anatomy imposes high intrinsic load, as there are several units of information to be learned, and these units of information are correlated with each other. Moreover, intrinsic load also depends on learners' prior knowledge, whereby those who have prior knowledge of the learned materials will experience low intrinsic load while learning (33). By manipulating the intrinsic load, a teacher would be able to reduce the perceived difficulty of the instruction.

On the other hand, the extraneous load is imposed by suboptimally designed instructional materials and distraction (33). The extraneous load is high when instruction is poorly designed or when there is a distraction. This form of cognitive load hampers learning and therefore needs to be reduced. However, the germane load, which is a misnomer, refers to the cognitive resources that are being invested by the learner to process the learned information (i.e., intrinsic load). Therefore, germane load, which does not contribute to the total cognitive load, needs to be increased to enhance learning. Hence, this load is imposed when the learner expends extra cognitive effort to understand the instructional material (33). This load could be visualised by the learners' motivation, self-determination and perseverance.

For learning to occur, the CLT states that total cognitive load, which is the summation of intrinsic and extraneous loads, must not exceed the human working memory's capacity (30). Hence, it is important to ensure that these loads are reduced so that the available working memory resources (i.e., germane load) could be used to process more information during learning. CLT researchers have introduced various strategies, which have been proven to successfully manage, reduce and increase the intrinsic, extraneous and germane loads (26, 32–33, 44–45). The effect of these principles on integrated instruction is deliberated in this article.

COGNITIVE PROCESSING OF INTEGRATED ANATOMY CONTENT

Teaching integrated content has been a challenge for medical teachers, including anatomy lecturers. Implementation of horizontal integration among topics of different anatomy subdisciplines (i.e., gross anatomy, histology, embryology and neuroanatomy) or with other basic science subjects (i.e., physiology, biochemistry and pathology) in one teaching session is not a common practice for undergraduate medical curriculum (46). Likewise, a full-blown implementation of vertical integration between the subject of anatomy and clinical subjects is not without hurdles, as it requires lecturers' commitment from various disciplines to contribute in the development and transfer of instruction

(47). Despite these challenges, the design and delivery of integrated anatomy content has been reported in several articles. For instance, traditional anatomy and physiology lectures on circulatory system were supplemented with computer assisted learning (CAL) multimedia on vital signs with animation and audio features to promote students' engagement, exploration, explanation, elaboration and evaluation (i.e., the 5Es instructional model) of the instruction (48). In addition, learning anatomy through an explorative learning approach has been described in a gross anatomy course, whereby students learned anatomy and physiological process through clinical skills and reasoning. In this reverse learning approach, students were introduced to a patient, from whom they explored the clinical presentation and related it to gross anatomy knowledge (49). Likewise, a reverse learning, horizontally integrated instruction that adopts "Physiology-then-Anatomy" (Phy-Antastic) approach was reported to be a potential way to promote deep learning in anatomy (50). These strategies of teaching integrated content comply with some CLT principles: namely, modality and goal-free effects. The modality effect, seen in the use of computer-assisted instruction (CAI) multimedia, describes the effective use of two learning modalities, which are visual information accompanied with spoken narration in enhancing learning as it reduces the extraneous load (32). The goal-free effect posits that problems with non-specific goals enhance learning compared to conventional problems with goals, as it allows exploration of knowledge by the learners (51).

Furthermore, several studies have provided ample evidence on the effectiveness of integrated instruction, whereby this form of instruction has been proven to increase knowledge acquisition and achieve higher student perception for comprehension of the subject (52–54). It has also been proven that integrating basic science subjects, including anatomy, with clinical subjects improved students' conceptual knowledge as well as skill retention and transfer (29). Furthermore, the integrated anatomy content should be longitudinally taught across different phases of undergraduate medical curricula, as clinical year medical students may benefit from the revision of basic science knowledge for the clinical reasoning process (55).

The CLT has proven that integrated instruction has advantages for learning (33, 56). When learning integrated anatomy instruction, students would be able to visualise the connections among various subject areas through definite links that were made explicit during teaching. This form of physically integrated format preserves the working memory resources that could be used to mentally integrate the connection if the instructions were taught separately. Physically integrating the relationships among the units of information allows the students to direct their working memory resources to process new schema (i.e., learning new things from the integrated instruction). Hence, the split attention effect of the CLT could be prevented, where students would not need to split their attention between two different sets of material that are separately taught (57).

Moreover, learning an anatomy topic in isolation hampers students' understanding of why they need to learn the topic. Without integrating the clinical application of the topic, students would not be able to justify the relevance of learning the topic, therefore suppressing their internal motivation to learn (52). Normally, a non-integrated anatomy teaching focuses on covering the width and depth of a topic, which is cognitive-intensive and lacking in terms of conceptual explanation and clinical relevance (53). In this condition, students would not be able to appreciate the gist of learning a dry subject and would end up learning anatomy through rote memorisation (58). Consequently, there would be a high possibility that students learn anatomy through a superficial approach as they would lack internal motivation. In the CLT context, having an internal motivation is relevant to learning as it ensures the sustainability of the cognitive processing (i.e., germane load) during learning. Without internal motivation, available working memory resources are diverted to process other information, which is extraneous to learning and thus hampers students' understanding.

Hence, it is important to incorporate the clinical application in anatomy teaching and learning (59). Today, more clinicians support the vertical integration of anatomy teaching through case-based learning and their support towards vertical integration is due to its effectiveness in promoting independent reasoning and improving problem-solving skill that is important for future doctors (60). It was also noted that students were satisfied with integrated lectures compared to conventional lectures as they perceived it easier to understand the lecture content (61). Learning anatomy through clinical cases stimulates interest among students and helps them to solve medical problems (62).

In addition, learning integrated anatomy content could trigger the self-explanation effect of the CLT. This effect is observable when integrated anatomy content is delivered to clinical year medical students who have gained anatomy knowledge during their pre-clinical year study. The self-explanation effect explains the fact that learners who have acquired a certain level of experience and skill would be able to use their stored schema to self-explain the learned material (63). Even though the self-explanation effect is a subconscious element during learning, students consciously allocate their cognitive resources in an attempt to provide worked-out solutions to their query and to coherently link the solution steps (64–65). Hence, imparting a related anatomy input into clinical instruction could trigger their minds to provide conceptual justification of a clinical scenario, therefore allowing them to have good clinical reasoning. This form of cognitive load effect stimulates the germane load that is required for learning.

Likewise, the germane load can also be stimulated in pre-clinical year medical students when they learn through integrated instruction. An integrated anatomy instruction provides various examples that could be viewed from different discipline perspectives. For instance, ligamentum teres hepatis is viewed as a cord-like ligamentous structure that connects the liver to umbilicus in gross anatomy, but in embryology, it is the remnant of the fetal umbilical vein that has been obliterated. In the clinical context, the ligamentum teres hepatis can be learned as "abnormal" when it fails to be obliterated after two months of life, and it can also be correlated with paraumbilical veins (which remain patent after birth) that travel alongside the ligamentum teres and contributes to portosystemic anastomosis. The various views of learning an anatomical structure in this condition is known as the variability worked-example effect of the CLT. Previous studies have demonstrated higher task performance for learners learning worked-examples with variable surface structures, compared to those learning worked-examples of similar surface structures (66). Hence, variability effect is assumed to be related to germane load, as the learners need to engage with different categories of information with different surface features (30).

COGNITIVE PROCESSING DURING INTEGRATED ANATOMY TEACHING APPROACH

It is evident from the literature that there is no single effective teaching method in anatomy (15, 67). In general, the teaching of an anatomy topic in several medical schools begin with a lecture-based instruction followed by subsequent student-centred learning activities (i.e., anatomy practical, TBL and PBL). Over the past decade, anatomists began to use digital instruction, such as e-learning, mobile learning (m-learning) and massive open online course (MOOC), to facilitate content delivery of anatomy input before and after lectures, thus resulting in the emergence of flipped classrooms (68–70). Moreover, some institutions have been using virtual reality and artificial intelligence tools to vary their teaching approaches and learning activities (71–72). The cognitive theory of virtual reality learning posits that virtual reality is superior than multimedia learning as it promotes perceptual richness (73). A study by Küçük et al. (18) demonstrated that mobile artificial reality applications led to higher learning performance through the minimisation of ineffective information seeking, thus consequently reducing students' extraneous load (74).

Likewise, teaching integrated anatomy content to clinical year students has been widely practiced, namely in radiology and surgical disciplines (75–76). Studies have demonstrated that integrated anatomy teaching led to better student performance in anatomy compared to compartmentalised teaching (70–72). The integrated teaching approach is expected to cater to differences in learning style and to promote experiential learning (77). Experiential learning allows students to have experience in completing tasks, which then enables them to reflect and conceptualise the content of the learning task, as well as permitting the improvement of metacognitive skills through a repetitive cycle of surveillance and reaction towards mistake (78). Hence, students who are exposed to several learning processes in integrated teaching would have good long-term retention of the knowledge. This could be explained by the CLT principle, whereby learning through reflection and conceptualisation through experience requires extra cognitive effort to process information. The effortful cognitive processing that is devoted to learning is a source of germane load, which in turn promotes learning. Furthermore, the cognitive processing that is expected to occur during this learning situation fits the description of the variability worked-example and the self-explanation effects of the germane load as previously described.

In addition, integrated teaching will encourage students to actively participate in their learning process. Felder and Brent (79) described active learning as student participation in learning activities, either as individuals or in teams, alternating with guided instruction provision through discovery of new information. In anatomy education, there is a positive shift towards the use of the student-centred learning approach to complement didactic pedagogy. This fact is in line with the guidance-fading effect of CLT, whereby provision of information or guidance is gradually diminished as students acquire more experience in learning the topic (80).

CHALLENGES AND THE WAY FORWARD

Even though integrated anatomy content and teaching are supported by CLT principles, the implementation of the teaching process requires laborious planning. The major hurdle to the full practice of integrated teaching lies in the medical curriculum itself. Although many medical schools practise integrated or hybrid curricula, the content and teaching process are not holistically integrated. Learning outcomes, teaching sessions and assessment questions of a basic science subject, including anatomy, are still compartmentalised according to respective disciplines. It is difficult to gather lecturers from various disciplines, especially from clinical departments, to plan, prepare and execute the teaching. Furthermore, preparation for integrated teaching content requires extra effort and time. With heavy teaching, research and administrative workload, it would be highly unlikely for lecturers to comply with teaching across disciplines, which is something they are not trained for or familiar with (81).

Nevertheless, it is noteworthy to mention that integrated anatomy content and teaching approach may be applicable in the future in view of the emerging use of modern digital technology that focusses on application of knowledge (82). Ever since the COVID-19 pandemic, online learning and digital content have been used widely in medical education (83). It has been argued that digital technology would allow the enhancement of multimodality teaching (71). For instance, the use of Complete Anatomy software that contains more than 17,000 3D diagrams and clinical applied videos allows the execution of virtual dissection concurrent with the discussion of microscopic anatomy, pathological conditions and clinical application (84).

On the other hand, lecturers need to be creative in finding ways to introduce integrated anatomy content and teaching approach. Studies have demonstrated that using creative approaches like performing-arts related presentation such as poems, stories, songs, skits, monologues riddles video, games drawing poster and cartoons, could enhance medical students' critical, observational and diagnostic skills (85). The spontaneous storytelling approach was also found to be effective in developing students' reflective ability in the face of dealing with clinical anatomy problems (86). Poetry was also found to be well related with the medical course as it allowed students to have a first grab on the person problem and followed by controlling the reality of human crisis or hardship (87). Creative writing and role play may also assist students to retain information and to build up and connect their knowledge in a useful way (88).

Nevertheless, to ensure optimal learning, it is important to select essentially relevant information and activities that can trigger critical thinking, self-explanation and motivation to learn. Unnecessary extra information would impose extraneous load on learners and can hamper learning as described by the CLT redundancy effect (89). Hence, it should be noted that an integrated anatomy instruction that is not prepared according to CLT principles may result in cognitive overload. Although the mechanism of cognitive processing for integrated anatomy instruction is primarily through the germane load effect, the main source of cognitive load during preparation and delivery of instruction comes from extraneous load. Apart from eliminating unnecessary information in integrated instruction, the general plan and layout of the content and teaching session should be well organised to reduce distraction. This effort would reduce learners' extraneous load. On the other hand, teaching integrated instruction content should follow the isolated interacting element effect of intrinsic load, whereby the content from each discipline should be introduced briefly in isolation, followed by a summary of the whole content by introducing the connection among them. This teaching strategy ensures development of prior knowledge before learning the integrated version of the instruction, thus promoting learning.

CONCLUSION

This article unearths the theoretical foundation of integrated teaching content and approach in anatomy education. Several strategies for designing and delivering integrated anatomy content were suggested, namely through student-centred learning and application of digital content instruction. Nevertheless, it is premature to suggest the effectiveness of anatomy integrated instruction until it has been proven in a well-designed research environment. The mechanism of action for integrated anatomy instruction should also be explored to confirm its causal relations with human cognitive function. With clear understanding of the effectiveness of integrated instruction, strategic planning of curriculum modification, teachers' professional development and provision of teaching-learning facilities could be conducted successfully.

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