

Anatomy of Learning: Instructional Design Principles for the Anatomical Sciences

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Teaching anatomy is becoming increasingly challenging due to the progressive evolution of university teaching missions, student populations, medical and undergraduate curricula, coupled with a paucity of empirically tested evidence-based instructional practices in the anatomical and medical education literature. As a mechanism to confront these pedagogical challenges, recent advances in educational psychology are analyzed for developing a framework to guide educational reform efforts. Extensive research in educational psychology over the last 100 years has resulted in four major theories on human learning that have facilitated a paradigm shift from teacher-centered to learner-centered classrooms and are described here in temporal order of development: behavioral theory, information processing theory, metacognitive theory, and social constructivist theory. Each theory is analyzed in detail and is used to construct instructional design principles for enhancing anatomical education research and practice. An example of a cognitively based learning environment for an undergraduate anatomy course is presented. Preliminary results suggest that intentionally drawing on different theories of learning when making instructional decisions gave students the learning support they needed to be successful and nearly doubled the course's student retention rate over a 3-year period. *Anat Rec (Part B: New Anat) 289B:252-260, 2006.* © 2006 Wiley-Liss, Inc.

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INTRODUCTION

Anatomy educators are currently facing many of the most daunting pedagogical challenges among courses taught in the medical and biological sciences. Teaching missions in tertiary education are being reformed from simply providing instruction to producing student learning, which pressures faculty to develop learner-centered approaches to teaching (King, 1993; Barr and Tagg, 1995). Students are rapidly becoming more technology-dependent; diverse in mo-

tivation, prior knowledge, and aptitude; and overburdened with nonacademic responsibilities, time constraints, and financial pressures (Miller et al., 2002; Reidenberg and Laitman, 2002). Anatomy educators are expected to teach more students and more content as the practice of medicine requires an increasingly large, enriched, integrated, and applied knowledge base (Onion and Slade, 1995; Tarek, 1999) with fewer resources as budgets are cut and anatomy contact hours are reduced. Undergraduate anatomy educators are confronted with low student achievement and retention rates, an academically diverse cohort of students, and the preparation of students for admission into a vast array of competitive health science programs (Miller et al., 2002). It is now more important than ever to make anatomical instruction increasingly maximized, efficient, and lifelong.

Evidence-based medical education practices are sparse in the literature (Hart and Harden, 2000) and add to the challenges facing anatomy educators. Most instructional advances in anatomical imaging and viewing have

not been tested empirically for impacts on student learning. Although educational literature on a wide variety of classroom teaching techniques is vast and well intended (Lechner, 2002), most techniques were developed haphazardly through trial and error in the classroom with little awareness to the underlying theories of learning (Marrone and Tarr, 2005). Often, the techniques' projected impacts on learning fall short upon investigating the validity of the supporting evidence (Halpren and Hakel, 2003). The traditional preparation of college faculty through an intense study of a scientific discipline with little to no formal training in college teaching and human learning results in faculty teaching the way they were taught (Halpren and Hakel, 2003) and contributes to the paucity of evidence-based practices. Consequently, research in medical education is needed and ongoing evaluation of instructional innovations must be an integral part of educational advance (Van Der Vleuten et al., 2000).

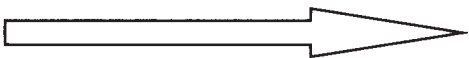
A strategic opportunity now exists

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TABLE 1. Four theories of human learning

Model Theories	Behavioral Model		Cognitive Model	
	Association Theory	Information-Processing Theory	Metacognitive Theory	Social Constructivist Theory
Goal of Learning	To acquire facts, skills, & concepts	To acquire facts, skills, & concepts	Learn how to learn	Construct new knowledge
View of Knowledge	Fixed & held by instructor	Fixed & held by instructor	Two types exist: content & cognitive knowledge	Held by both instructor & learners, always developing
View of Instructor	Dispenses facts & shapes behaviors	Dispenses facts & helps students understand	Dispenses facts; teaches students how to learn	Facilitator and co-participant
View of Learner	Passive respondent to stimuli	Mental processor of information	Active regulator of all learning processes	Active constructor of knowledge in a social context
Learning Strategy	Memorization, drill & practice, rewards & punish	Prior knowledge activation, organize content, strategies	Goal setting, Planning, Self-testing & reflecting	Discussion, PBL, collaboration, reasoning
Interaction with Peers	Usually none	Usually none	Can influence learning	Necessary as students learn from each other
Locus of Responsibility for Learning	Instructor responsibility			

Adapted from Marrone and Tarr, 2005; Woolfolk, 2001, p. 358; Mayer, 1992.

to utilize recent and extraordinary advances in educational psychology to guide medical and anatomical education research, reform efforts, and practice. Educational psychology was initially founded in 1906 by Edward Thorndike, who argued that the experimental methods of exact science should be applied to the problems of education, learning, and instruction (Thorndike, 1906). Educational psychology now conceptually stands at the crossroads between educational practice and scientific research on human learning. Research is vast and widespread across topics of cognition, memory, problem-solving, expertise, motivation, and instructional design (Gagne, 1985; Thomas, 1988; Resnick, 1989). Educational psychology research over the last century has waned from a behavioral model to a cognitive model and is based on four major views or theories on learning (Table 1) (Mayer, 1992, 1996; Walberg and Haertel, 1992; Woolfolk, 2001; Marrone and Tarr, 2005). Understanding learning theories provide anatomy educators with an awareness of when and why different instructional approaches might be used to give students the learning support

mechanisms they need to be successful (Marrone and Tarr, 2005).

FOUR VIEWS ON LEARNING

Behavioral Model

During its tenure as the dominant educational psychology theory of the first three-quarters of the 20th century (Greeno et al., 1996), the behavioral model defined learning as a mechanistic process in which associations were developed that were automatically strengthened or weakened in response to environmental feedback (Mayer, 1992, 1996; Svinicki, 1999). The goal of instruction was to shape student learning externally by increasing the frequency of correct responses and minimizing errors using rewards and punishments. The human brain was viewed metaphorically as an empty container or blank slate into which external knowledge was dispensed passively. The role of the instructor was to be the central figure, the "sage on the stage," who transmitted knowledge through factual-rich lectures (King, 1993). The role of the student was to listen, record notes, memorize information, and reproduce it later on an examination. Learning strategies

were superficial and required very little if any thought and consisted of drill and practice, memorization, repetition, and recitation (Table 1) (Mayer, 1996; Svinicki, 1999; Gredler, 2001: p. 68; Marrone and Tarr, 2005).

Instructional implications

A few beneficial legacies of behavioral theory still exist in contemporary instruction, despite much of it no longer being vogue. Arguably, the most noticeable is that of organizing course content around specified course objectives. Using statements such as "the student will be able to describe the attachments and innervations of the musculature of the thigh" helps both the student and instructor identify intended target behaviors and specific levels of understanding. Other instructional descendants include mastery learning, self-paced instruction, and criterion-referenced evaluation (Svinicki, 1999).

Cognitive Model

The cognitive model of learning has dominated educational psychology since the beginning of the fourth quarter of the 20th century, when the

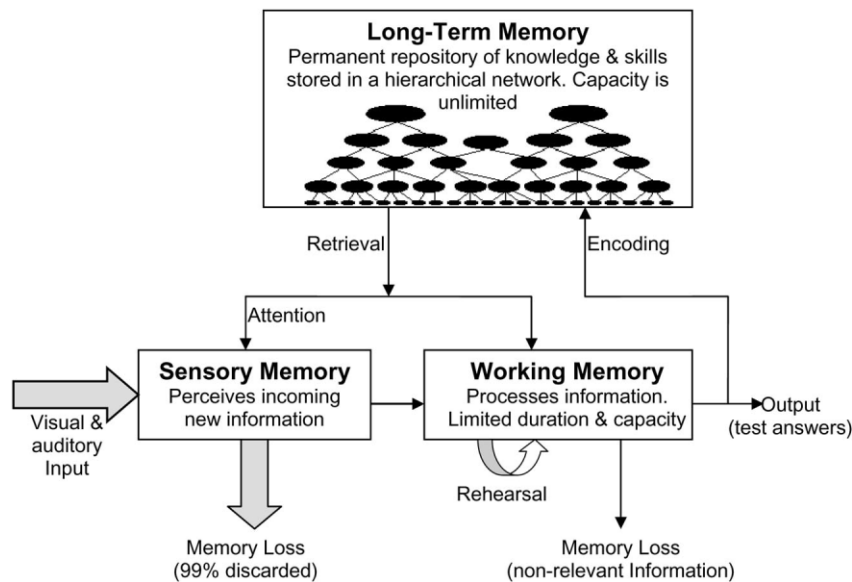


Figure 1. The cognitive architecture of the human memory system based on information processing theory.

influence of the learner began to be considered in the learning process. Human cognition refers to the mental mechanisms by which we come to learn or know something. Major theories have progressively developed that help to understand human cognition (Walberg and Haertel, 1992) and can serve as theoretical foundations for anatomical and medical education research and practice. Three major theories include information processing theory, metacognitive theory, and constructivist theory (Table 1).

Information Processing Theory

Information processing theory defines learning as an active mental process involving the storage and retrieval of knowledge stored in memory. Information processing theory provides a model of the cognitive architecture and mental processes of the human memory system (Fig. 1). The cognitive architecture of memory is represented as a series of three discrete memory subcomponents: sensory memory (SM), working memory (WM), and long-term memory (LTM), which perform stepwise mental processes to acquire, process, store, and retrieve information.

The SM component acquires a continual stream of new information from the auditory and visual sensory systems (Fig. 1). Selective attention and perception initially process the

acquired information to extract relevant elements (about 1%) and to discard nonimportant elements (Sperling, 1960; Breitmeyer and Ganz, 1976; Cowan, 1990). New information that has been attended to and perceived is transmitted to working memory. Factors influencing attention and perception include prior knowledge and visual/auditory characteristics of intensity, novelty, and emotional attachment (Marr, 1985; Bruning et al., 1999). The duration of storage and processing is very brief, a maximum of 3 sec (Chase, 1987).

The WM component, commonly referred to as short-term memory, is the central information processor of the memory system (Fig. 1) (Baddeley, 1986). It is the embodiment of human consciousness, the only memory component where the awareness of information exists (Sweller et al., 1998). WM receives new information transmitted from SM and prior knowledge retrieved from LTM. Prior knowledge is used to filter new information selectively for meaningful, useful elements; nonselected items are rapidly discarded from WM (Craik and Lockhart, 1972; Bruning et al., 1999). Selected elements are organized, processed, and encoded for storage in LTM or to generate cognitive output, such as problem-solving and generating answers to test questions. The capacity of WM is limited in duration

and volume. Duration of storage is short, lasting for 5–20 sec unless information elements are kept active through rehearsal processing. Volume for simply holding new information is limited to a maximum of nine elements simultaneously (Miller, 1956) and volume for complex processing is severely limited to only two or three elements simultaneously (Sweller, 2004).

The LTM component is the storage repository for learned knowledge and skills (Fig. 1). It is now widely accepted that learner expertise, competency, and the ability to transfer and apply knowledge to a new event are heavily and possibly solely dependent on the extent and elaboration of knowledge stored in LTM (Gredler, 2001; Sweller, 2004). Storage capacity and duration of LTM is theoretically unlimited, although retrieval over time becomes increasingly difficult (Houston, 1991).

Schema theory suggests that learned knowledge in LTM is stored in schemas, which are hierarchical knowledge structures that meaningfully categorize elements of related information into an intricate serial network of interrelated and interlinked connections (Fig. 1). Schemas act as a central executive in organizing new information in WM to be subsequently encoded into LTM (Merriënboer and Sweller, 2005). Encoding new information modifies schemas through the expansion of an existing schema, reshaping of interconnections between existing schemas, and restructuring of the knowledge network to form new schemas (Bruning et al., 1999). Schemas are arranged in an organized fashion that promote rapid, on-demand recall and conceptual understanding (Chi et al., 1982). Elaborately interconnected schemas allow for the activation of one schema to activate other closely associated and linked schemas, which facilitate the retrieval of prior knowledge elements into WM for use (Craig and Lockhart, 1972; Greene, 1992). Consequently, retrieval ability is influenced by the amount of schema elaboration and when the conditions at retrieval match those that were present at the time of encoding (Bruning et al.,

1999). Therefore, instruction and learning must be closely linked with assessment.

Cognitive load theory suggests that student intellectual performance is optimized when the limitations of WM capacity are used as determinants to guide the development of effective instructional designs that intentionally manage cognitive resources when learning new, unfamiliar information. Cognitive load refers to the total amount of mental activity imposed on WM at an instance in time. The fundamental principles of cognitive load theory assume that WM is very limited in capacity when processing new, unfamiliar information; WM is actively engaged in comprehension and processing activities when learning; and learning will be ineffective if the cognitive resources of WM are exceeded. Cognitive load-based instructional designs intentionally reduce the cognitive load of a learning task to allow available WM resources to be more fully devoted to process, comprehend, and encode the new information. Cognitive load theory has been shown empirically to provide strong benefits to learners, including improved learning efficiency and performance on test problems and transfer problems of clinical application (Kyllonen and Christal, 1990; Chandler and Sweller, 1991; Sweller et al, 1998; Pass et al., 2004; Sweller, 2004; Merrienboer and Sweller, 2005).

Instructional implications

The goal of information-processing based instruction is to design instructional methods and materials that increase the amount of information in the student's LTM knowledge network so that learning outcomes can be assessed by measuring the amount of knowledge acquired (Table 1). The role of the instructor is to transmit knowledge to students through designing curricula, developing lectures, and modeling learning strategies. The role of the student is to acquire knowledge and use learning strategies to gain a more complete understanding of the course content. Textbooks and lectures become the focus of educational research and practice (Mayer, 1996; Svinicki, 1999; Marrone and Tarr, 2005).

Given the sheer volume and spatial complexity of anatomical information to be acquired by students, instructional design principles based on information processing and cognitive load theories (e.g., Yates and Chandler, 1991; Cust, 1995; Regehr and Norman, 1996; Gruppen, 1997; Reese, 1998) suggest that anatomy educators should accomplish the following.

One, activate prior knowledge in LTM. The starting point of learning or what can be learned depends substantially on what students already know. Stimulate students' retrieval of prior knowledge into WM at the beginning of each lecture by reviewing major concepts from previous lectures, providing analogies to upcoming new content, initiating intellectual and affective responses to content, or arousing curiosity through posing an interesting clinical application. Activated prior knowledge directs attention processes in SM and organizes new information in WM for subsequent encoding into LTM.

Two, focus student attention on important concepts and remove nonessential explanatory detail. In lecture, visually highlight main ideas and articulate key points more slowly and loudly. Select a text wisely that adequately covers the desired course content. Explicitly indicate the important information to be learned. Otherwise, without adequate focus, students will have difficulty in selectively filtering new information for relevant items and will expend cognitive resources to learn every minute detail, which rapidly overloads WM.

Three, provide the content to be learned. Make lecture presentations clear and concise to cover the intended course objectives adequately. A lecture with insufficient information needed to complete a learning task forces the student to search and create missing information, which rapidly overloads WM.

Four, integrate multiple sources of information into a single coherent source. Different visuals, Web sites, texts, and other sources of information should be expertly integrated together so that the student can focus attention and cognitive resources on one major source. Multiple sources of disparate information require the student to split attention across the vari-

ous information sources, which increases cognitive load on WM (Mousavi et al., 1995).

Five, effectively organize information to reveal hierarchical conceptual relationships. Present lecture notes in an outline format that reveals hierarchical interrelationships among concepts, structures, and finer detail. Improved lecture organization allows the student to focus on encoding processes, rather than having to consume resources on organizing, categorizing, and mentally forming relationships between elements of information, which rapidly overloads WM.

Six, reduce redundancy and unnecessary repetitive processing of information. Select or create visuals that are mostly free of excessive explanatory textual items and present explanatory descriptions audibly in lecture. This focuses the students' cognitive resources on visualizing the structure of interest, rather than the student viewing the structure and reading the detail simultaneously, which unnecessarily increases cognitive load.

Seven, break up the lecture to provide students with time to process information. Provide a short opportunity (5 min or less) in lecture for students to process newly acquired information. Providing a second example, asking a question, or having students discuss in small groups an application or clinical case requires students to learn in lecture rather than to simply record notes. A continual stream of new information during a 50-min lecture cannot be processed rapidly enough by most students and quickly overloads WM.

Eight, promote distributed or continual practice over massed practice. Provide a second example that elaborates on the concept presented in lecture. Assign homework and other supplementary or technological activities that put the new information into practice. Give a comprehensive final examination to reinforce the major course objectives and to reactivate newly formed schemas. These learning strategies facilitate more continual processing and encoding of the course information as opposed to massed practice or intense cramming the night before an examination, which rapidly overloads WM.

Nine, guide the learning of students.

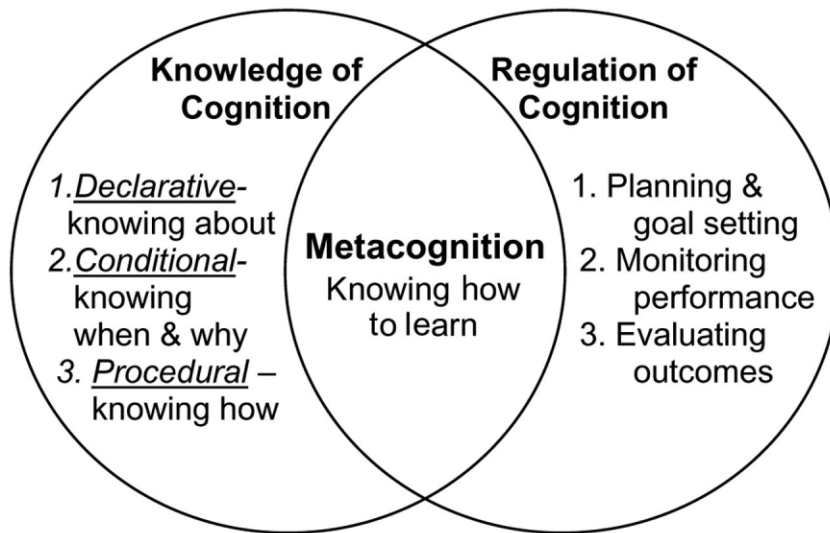


Figure 2. Metacognitive knowledge elements and regulation activities.

Provide guided notes of lecture content as mediation between distributing a complete copy of PowerPoint slides and not providing any handouts. Guided notes is a method of note-taking in which a hierarchical outline of the lecture presentation is provided to students with several key elements intentionally omitted. Students attend carefully to the lecture presentation to record the missing elements. Guided notes helps to reveal the interrelationships between the various parts of a topic, ensures students they have a complete set of notes, increases the efficiency of note-taking, and reduces the mental energy required for taking notes, which in turn enables students to better listen to and mentally process the lecture.

Ten, actively teach learning strategies that encourage students to go beyond rote memorization. Encoding of simplistic information (e.g., anatomical structure names) can be enhanced using strategies of rehearsal, drill, and practice, making mental image representations, and mnemonics. Encoding complex information (e.g., organization of forearm muscles, spinal column tracts) can be enhanced by using advance organizers, categorizing, and chunking. Ask questions that require application and transfer of the new information. Have students draw structures and concept maps.

Metacognitive Theory

Metacognition (Table 1) is “thinking about thinking” or “knowing how to learn.” It has been defined in the literature as a body of knowledge and understanding that reflects on the processes of cognition itself. Although information processing theory took into account prior knowledge and memory processes of the learner in order to make recommendations on how to design effective instructional materials, metacognitive theory views the learner as a full and active participant in the learning process who can consciously control and direct cognition while engaged in learning (Schraw, 1998; Svinicki, 1999). A learner with good metacognitive skills can take conscious control of their learning task, plan and select appropriate learning strategies, monitor the progress of learning, correct errors, and adjust learning behaviors and strategies when necessary (Ridley et al., 1992; Winn and Snyder, 1998).

Metacognitive theory is based on the integration of a learner’s knowledge and regulation of cognition (Fig. 2) (Brown, 1978; Brown et al., 1983; Schraw and Moshman, 1995; Schraw, 1998). Knowledge of cognition is the body of information, understanding, or awareness a learner has about their own cognitive processes. Skilled learners possess three elements of knowledge about cognition that have

been shown to improve learning: declarative, procedural, and conditional knowledge (Schraw and Moshman, 1995; Schraw, 1998). Declarative knowledge consists of knowing what factors influence learning performance, such as having a large repertoire of prior knowledge and learning strategies (Pressley et al., 1987; Schneider and Pressley, 1989). Conditional knowledge involves knowing when and why to select the most effective learning strategies in order to better regulate learning and achieve a desired learning task (Reynolds, 1992). Procedural knowledge refers to knowing how to execute the selected learning strategies (Stanovich, 1990). Skilled learners are able to activate prior knowledge, possess a large repertoire of learning strategies, automatically rank available strategies on their perceived level of effectiveness, select the most effective strategies, and know how to use the selected strategies to achieve a desired learning task.

Regulation of cognition is the active controlling of the cognitive processing of new information. Three regulatory activities are used by skilled learners to improve learning (Fig. 2): planning, monitoring, and evaluation (Schraw and Moshman, 1995; Schraw, 1998). Planning involves setting learning goals, estimating the time and effort needed to complete a learning task successfully, and gathering helpful learning materials. Monitoring involves generating feedback through self-questioning and self-testing and then making subsequent adjustments to the learning process to improve performance and efficiency. Evaluation involves analyzing the outcomes of the learning process to determine whether the learning goal was achieved and how to improve the learning process for future learning tasks (Brown et al., 1983; Flavell, 1987). Skilled learners exhibit cognitive regulatory competence in order to enhance awareness of comprehension breakdowns.

Instructional implications

The goal of metacognitive-based instruction in anatomy education is to enhance intentionally the students’ self-knowledge and self-regulation of

their own cognition in order to help students improve their learning processes and become more independent. It places more responsibility of achievement to students (Table 1). Under this model of instruction, the role of the anatomy instructor is twofold: to transmit anatomical facts, skills, and concepts and to promote general metacognitive awareness and use. Metacognitive-based instructional design principles that can enhance the metacognitive skills in anatomy students include the following.

One, promote awareness that metacognition is vital to successful and self-regulated learning. At the beginning of a course, discuss the importance of knowing how to learn and how to monitor and regulate progress in learning. In lecture, provide time (5 min) for self-reflection and self-testing of the course content through group discussion (Rogoff, 1990). Explicitly model metacognitive skills on how anatomists think about human structure and function and how anatomists monitor their learning performance. The more explicit this modeling, the more likely it is that students will develop metacognitive skills (Butler and Winne, 1995).

Two, improve declarative, conditional, and procedural knowledge of cognition. At the beginning of each lecture, help students activate prior knowledge and focus attention by having students make predictions about information that will likely be presented in lecture on the basis of information learned from the previous lecture. Give an overview of the main topics to be taught to help students construct a conceptual overview. Relate main ideas when learning complex information to help students reduce cognitive load and to promote a deeper level of processing. Instruct and cue students on effective learning strategies while teaching specific anatomical content (Swanson, 1990; Pressley and Schneider, 1997).

Three, improve regulation of cognition through helping students plan, monitor, and evaluate their learning tasks. For each unit taught (e.g., head and neck or the respiratory system), prompt students to form a goal (e.g., "I want an 'A' grade on the next examination") and then prompt them to estimate the time and effort needed to

TABLE 2. A regulatory checklist for students to improve their metacognitive skills

Planning	
1.	What is my goal and purpose for learning this information?
2.	How much do I already know about this topic?
3.	How much time & resources will I need to accomplish my goal?
Monitoring	
1.	Am I reaching my goal?
2.	How well am I doing?
3.	Do I need to make changes to my strategies?
Evaluating	
1.	Did I reach my goal?
2.	What worked and didn't work?
3.	How will I improve next time?

accomplish their goal. Encourage student self-reflection and self-testing by providing homework assignments or practice quizzes. After each unit examination, ask students if they met their goal and how to learn better in the next unit. Also, encourage students to use a regulatory check list (Table 2) that systematically helps control performance. A regulatory check list should contain the three main categories of regulatory activities used by skilled learners (Schraw, 1998). Teaching metacognitive skills helps to improve student efficiency in learning.

Social Constructivist Theory

Social constructivist theory (Table 1), pioneered by Lev Vygotsky (1978), defines learning as a collaborative social process involving the coconstruction of knowledge among a community of learners. The importance of the context in which learning occurs renders situations and events meaningful and relevant to the student by providing opportunities to construct new knowledge from authentic experience. Learning is viewed as a socially active, constructive, and cumulative process that does not occur from simply recording knowledge into memory. New knowledge is assimilated and interpreted through iterative social processes, involving discursive, adaptive, interactive, and reflexive qualities (Marrone and Tarr, 2005).

Social constructivist theory adds a

collaborative social component to a constructivist view of learning. A constructivist view of learning defines learning as a process of knowledge construction. New knowledge is created by combining prior knowledge against new information. When new information is encountered, the learner uses interpretive cognitive processes of accommodation, assimilation, and equilibration to resolve perturbations in the coherence of his or her existing knowledge networks by coordinating and constructing new and more adequate cognitive structures (Saxe, 1991). Constructivism goes beyond the shaping of behaviors and the study of how the brain stores and retrieves information to examine the ways in which learners interpret and construct meaning from experience.

The goal of social constructivist-based instruction is to help students build on prior knowledge and to construct new knowledge in order to contribute to the richness of shared understanding within an integrated knowledge community (Table 1). It emphasizes learning and not teaching, encourages learner autonomy and personal involvement in learning, fosters learners' natural curiosity, and takes into account affective variables of the learners in terms of their beliefs, attitudes, and motivation. The role of the instructor is that of a facilitator and a coparticipant in the learning process who contributes to shared student learning through creating rich social interactions between students and course content, organizing authentic learning experiences, and creating constructive and collaborative learning environments. Learners are viewed as active constructors of new knowledge and understanding, as incumbents with significant classroom roles, and as agents exercising will and purpose. Students take responsibility for their own learning by framing questions, analyzing information, and establishing connections between facts in order to predict, justify, and defend their ideas (Shuell, 1986; Derry, 1996; Marrone and Tarr, 2005).

Instructional implications

Social constructivist-based instruction suggests that anatomy class-

TABLE 3. Cognitive-based instructional designs used in large lectures for an undergraduate human anatomy course

Instructional Practice	Associated Learning Theory and Principle
1. Explicitly-defined curricula and content	Information Processing Theory
2. Clear & text-free visuals available in a single source	Cognitive Load Theory
3. Use of guided notes in a lecture series manual	Cognitive Load Theory
4. Structured Collaborative Learning:	
a) In-class small group discussions	Social Constructivist & Metacognitive Theories
b) Collaborative assessment	Social Constructivist & Metacognitive Theories
5. Outside-of-class learning activities:	
a) Web-based audio recordings of lecture	Behavioral & Metacognitive Theories
b) Homework assignments	Behavioral, Info-processing & Metacognitive Theories

rooms should be viewed as a shared learning community and charged with the task of developing knowledge by engaging in collaborative practices from which anatomical concepts and ideas emerge. Throughout almost everyone's lives, people learn and work collaboratively, not individually (Brown et al., 1989). Consequently, collaborative learning environments should be designed to include student learning activities that are directly relevant to the application of learning (Brown et al., 1989) and should take place within an applied context that is representative of the true collaborative nature of the medical and health science professions. Social constructivist instructional design principles for anatomy educators include the following.

One, help students assimilate, accommodate, and interpret information. Provide opportunities that provoke reflective experimentation, discourse, and conceptual reasoning to lead to the construction and reconstruction of student anatomical knowledge.

Two, make instruction commensurate with the experiences that make students willing to learn. Develop contexts for learning that are highly applicable and useful in the medicine and health science professions. Teach in contexts that are personally meaningful to students. Engage students in groups to work on clinical case studies and problem-based learning.

Three, emphasize the importance of reasoning and mental skills. Instruction should be designed to facilitate extrapolation, which requires students to construct information that is beyond what is presented. Assessment should value meaningful activity instead of relying solely on correct answers through memorization

Four, use social constructivist instructional strategies. Teaching strategies based on social constructivism include class discussion, small group cooperative learning, reciprocal teaching, mentoring apprenticeships, problem-based instruction, and some forms of Web-based learning. Learning is successful when students can demonstrate conceptual understanding, not simply repeat what was taught.

COGNITIVE-BASED INSTRUCTION: A PRAGMATIC EXAMPLE

Instructional design principles founded on major theories of learning were used to improve the teaching and learning of undergraduate human anatomy in a large urban research university over a 3-year period. Cognitive-based instruction facilitates teaching excellence by promoting the development of innovative learner-centered pedagogy that supports student success, motivation, and lifelong learning. The cognitive model of learning (Table 1) was used as a diagnostic tool for isolating sources of difficulty in student learning; to identify places in the learning process where educational reform efforts would be most usefully deployed; and to serve as a framework for creating innovative instructional strategies to meet potentially the learning challenges identified by the model. This scholarship in teaching and learning adds a second dimension to the human anatomy classroom, from providing instruction and producing learning to creating a real-life educational laboratory for generating evidence-based teaching practices that work.

Five major instructional innovations were developed and implemented into the human anatomy lec-

ture and were consistent with cognitive hypotheses about the design of effective lecture experiences (Table 3). First, a needs assessment evaluated the anatomy curriculum to ensure adequate content coverage for students going into multiple health science programs. Explicit content was defined and lecture notes were outlined into a hierarchical format and computerized into PowerPoint. Intentions were to reduce cognitive load by providing the specific content to be learned so that students did not have to waste resources searching for missing content elsewhere and by explicitly depicting conceptual relationships among major topics and finer details.

The second innovation involved locating and/or creating clear, textual-free visuals that were added into the PowerPoint lecture. These visuals were made available to students as a single source through the creation of a digital library in the course's online course management system. Intentions were to reduce cognitive load associated with processing visual and auditory information simultaneously and to integrate disparate sources of information into one coherent source.

The third innovation involved creating a lecture series manual that contained most, but not all, of the lecture notes and was developed using cognitive load theory's instructional principle of guided notes. Students were expected to fill in missing key elements in the lecture manual by attending to the corresponding PowerPoint presentation. Intentions were to reduce cognitive load and increase efficiency associated with the note-taking process.

The fourth innovation consisted of developing two structured collabora-

tive learning activities (Table 3) on the basis of social constructivist and metacognitive theories: small group discussions and collaborative assessment. Small group discussions were used at the midpoint in nearly each lecture to break up the monotony of lecture and were made possible by the time saved through the use of the efficient guided note-taking procedure. Students in small groups were required to discuss and process course content by engaging in discourse, reasoning, and problem-solving activities to answer instructor-presented problem-based learning and clinical applications. Intentions were to encourage students to construct and elaborate on the meaning of the lecture content, check for understanding, and monitor their progress in their learning.

The second structured collaborative learning activity involved adding a cooperative learning component to the traditional lecture exam. After students completed a traditional multiple-choice lecture examination using individual efforts, students broke out into small groups to answer the same examination questions using collaborative efforts. Students were afforded the opportunity to debate, argue, reason, and articulate concepts in order to answer examination questions and to provide students with immediate feedback on their examination. This assessment strategy changed the focus of assessment from a summative evaluation (after the instructional event) into a formative learning event, which allows learners to learn from the assessment event itself. Intentions were to motivate students to overcome inhibitory feelings of isolation and anxiety, to promote self-discovery problem-solving strategies, to collaborate with peers, to resolve conflict, and to articulate concepts to peers, which are all good lifelong learning skills.

The fifth instructional innovation involved creating two tools for students to engage in distributed practice outside of the classroom. First, lectures were audio-recorded and made downloadable via the Internet. This gave students 24-hr access to audio information concerning lecture explanations of the course content. Second, homework assignments were devel-

oped that forced students to practice, process, and elaborate on course content.

These cognitive-based instructional design innovations significantly increased student learning, motivation, and retention. Although detailed statistical analyses associated with testing for the presence of incremental increases of each innovation is the purpose for subsequent articles, some significant trends are noteworthy. The course's retention rate was calculated on the basis of the DWF rate, defined as the number of students receiving final grades of D, W (withdrawal), or F (failing) for a 1-year period prior to and a 3-year period during implementation of the cognitive-based instructional practices. Results indicate that the course's DWF rate was reduced by 50% after the third year of using cognitive-based instruction. This corresponds to a doubling of the course's student retention rate in which over 50% of the students now received final grades of C or better. Also, analysis of course evaluations and qualitative surveys indicated improved student satisfaction with the course. Students felt more motivated and better prepared to learn when the cognitive-based instructional designs were used.

CONCLUSION

Educational psychology is well poised to help anatomy educators develop innovative instructional designs that reflect current ideas of best practice when confronting increasing pedagogical challenges and mission paradigm shifts. Information processing theory provides a model of the cognitive architecture and mental processes of the human memory system, emphasizing the importance of considering the limitations of working memory capacity in instructional designs. Metacognitive theory promotes autonomy in learners by promoting learner awareness of the knowledge of cognition and regulation of cognition. Social constructivist theory promotes deep learning and understanding by engaging students in constructing new knowledge through rich social interactions within an integrated knowledge community. No single theoretical approach is likely to achieve the

broad range of educational outcomes required for a complete understanding of the complexity of medical and anatomical knowledge. Cognitive-based instructional designs should be pragmatic and based on different theories of learning that give students the learning support mechanisms they need to be successful.

Educational psychology is also well poised to provide theoretical foundations for research in anatomical and medical education. Empirical studies on the impacts of instructional innovations on student learning must be an integral part of educational advance. It becomes the task of anatomy educators to develop and analyze new instructional practices for generating a body of empirically tested and validated practices in anatomy education.

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